ELECTRICAL SAFETY MANUAL

1.0 APPROVAL RECORD

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The official approval record for this document is maintained by Training & Documents.

2.0 REVISION/REVIEW INFORMATION

In accordance with the Ames Laboratory Document Control program, this manual will be reviewed at a minimum of every three years. The revision description for this document is available from and maintained by the author.

OVERVIEW OF SECTIONS AND APPENDICES

3.0 INTRODUCTION

This introduction provides a brief guide to the elements of this manual which establish the electrical safety policies of the Ames Laboratory and provides guidance for implementing these policies.

The electrical safety policies concern:

- **Administrative Controls:** Ensures equipment and buildings meet safety requirements (Section 2) and employees are properly trained (Section 3);
- **Safe Work Practices:** Provides guidance for general electrical work (Chapter 4), for grounding (Section 5), and for energized work (Section 6);
- **Electrical Integrity of Equipment:** Provides guidance and controls for equipment design (Section 7), for equipment acquisition and maintenance (Section 8), for tools and test equipment (Section 9), and for personal protection devices (Section 10);
- **Research and Development (R&D):** Addresses issues related to R&D laboratory practices (Section 11) and R&D equipment (Section 12); and
- **Building Equipment:** Ensures personnel safety during operation, maintenance, and repair of specific building equipment (Section 13).

The Electrical Safety Committee (ESC) recognizes that complete knowledge of all sections of this manual is not required by all employees. This manual assigns to group/section leaders the responsibility of ensuring all employees under their supervision receive appropriate training, employ safe work practices, and understand the portions of the manual applicable to their work environment.

3.1 Background

IF YOU WORK WITH EXPOSED ELECTRICITY OR SUPERVISE PEOPLE WHO WORK WITH ELECTRICITY, YOU MUST READ AND STUDY THIS MANUAL.

This manual is to be used as a resource to provide uniform guidance in reducing and/or eliminating risks associated with electrical related work practices. It establishes minimum safety requirements and safe work practices for the design, construction, installation, inspection, testing, operation, and maintenance of all low and high voltage electrical systems and electrical utilization devices/equipment for Ames Laboratory. This manual shall be used to supplement existing applicable Department of Energy (DOE) Orders, codes, standards, and regulations.

The DOE Electrical Safety Handbook *(DOE_HDBK-1092-2013)* defines the DOE electrical safety standards for DOE field offices and facilities. It provides a uniform set of electrical safety standards and guidance for DOE installations in order to effect a reduction or elimination of risks associated with the use of electrical energy. The objectives of this manual are to clarify electrical safety requirements, to enhance electrical safety awareness and to mitigate electrical hazards to employees, the public, and the environment.

3.2 Scope

The manual shall comply with the Integrated Safety Management System Policy and Plan. It is the policy of the Ames Laboratory to integrate safety into management and work practices at all levels to ensure workers, the public, and the environment are protected while the Laboratory's mission is accomplished. This includes the *Guiding Principles of Integrated Safety Management* namely:

- Line management responsibility for safety;
- Clear roles and responsibilities;
- Competence commensurate with responsibilities;
- Balanced priorities;
- Identification of safety standards and requirements;
- Hazard controls tailored to work being performed; and
- Operations authorization.

3.2.1 Scope of the Electrical Safety Program

Ames Laboratory work activities that can potentially affect workers, the public or the environment are defined, analyzed, developed, performed and reviewed according to the Laboratory's ES&H programs and practices. These work activities are subject to the core functions of Integrated Safety Management System (ISMS) with the degree of rigor appropriate to address the type of work activity and hazards involved. The ISMS core functions are:

- Define the scope of work;
- Analyze the hazards;
- Develop and implement hazard controls;
- Perform work within controls; and
- Provide feedback and continuous improvement.

Applicability: This manual shall apply to all employees, contractors, and visitors of Ames Laboratory. The manual is intended to give those persons, who in the course of their work activities may come into proximity with energized or potentially energized electrical parts, the minimum safety knowledge and recommended safe work practices necessary to protect themselves from potential electrical shock and/or burn hazards. It also provides information regarding the potential hazards for persons who utilize electrically powered equipment.

3.2.2 Scope of the Electrical Safety Manual

3.2.2.1 General Program Elements in the Manual

- Administrative Control
- Training Requirements for Qualified Electrical Worker
- Safe Work Practices
- Designing for Electrical Safety
- Acquisition, Fabrication, and Maintenance of Electrical Equipment
- Tools and Test Equipment
- Selection, Inspection, and Testing of Personal Protection and Testing Equipment
- Grounding

- Live (Energized) Work
- Research and Development
- Requirements for Specific R&D Equipment
- Requirements for Specific Building Equipment

3.2.2.2 Requirements

The requirements given in this manual shall not supersede more stringent requirements contained in other applicable codes, standards, and regulations. If more stringent standards or practices are decided upon for particular activities, Qualified Electrical Workers will be notified and this manual will be revised at the time of the next scheduled review.

3.2.2.3 Design

The design of new facilities shall conform to the requirements established by *DOE O420.1 Facility Safety*. The standards set forth in these orders, as they apply to existing facilities and operations, shall be used to determine whether the present systems and operations comply with the stipulated provisions or present a significant safety risk. If an evaluation determines that a safety risk exists, corrective actions shall be initiated to bring the system or operations into compliance with current standards. However, in case of a major renovation, the existing facility shall be brought into compliance with current standards. Existing facilities shall also comply with the provisions of the *Department of Labor (DOL) Occupational Safety and Health Administration (OSHA) standards 29 CFR 1910, Subpart S; and 29 CFR 1926, Subpart K, Electrical, and National Fire Protection Association (NFPA) 70E, Standard for Electrical Safety in the Workplace.* These standards have specific requirements that shall apply to all electrical installations and utilization equipment regardless of when they were designed or installed. In addition, these standards also identify other mandatory provisions and specify effective dates.

3.2.2.4 Applicability

Standards referenced in the manual shall apply to all new facilities. Existing installations need not be physically modified to comply with these standards unless DOE directives, and/or federal, state or local governments mandate correction, or an electrical safety assessment determines that corrective action needs to be initiated to address a specific electrical safety risk.

All facilities and organizations within Ames Laboratory jurisdiction will comply with the applicable portions of this manual and other pertinent electrical codes and standards.

3.2.2.5 Definitions

The standards referenced in this manual are either mandatory or advisory. Mandatory standards, denoted by the words "shall", "must", or "will", are requirements that must be followed unless written authority for exemption is granted by DOE. Advisory standards, denoted by the words "should" or "may", are standards that may be deviated from with a written waiver granted by the Authority Having Jurisdiction (AHJ) and approved by DOE. The waiver shall be based on a technical risk assessment and adequately documented. These advisory or mandatory standards have been drawn from existing criteria. A more complete definition of terms may be found in *Appendix B Definitions and Acronyms*.

3.2.2.6 Electrical Safety Knowledge

Knowledge of the specifics of this manual alone does not make a person qualified to work in close proximity to energized or potentially energized exposed electrical parts. Work practices shall be established within each work area, which include as a minimum, the specific electrical safety concerns/activities referenced by this manual. The content and quality of informal and formal field and classroom training, as well as establishing levels of experience in electrical safety work practices, shall be consistent with the requirements of the manual and the specific electrical hazard prevention of any operation being performed.

3.2.2.7 Preventive Maintenance

Preventive maintenance guidelines, where referenced in the manual, shall apply to all electrical equipment designated by line management (NFPA 70B as applicable).

3.2.2.8 References

In this manual, every effort has been made to include current applicable safety regulations, governmental and consensus codes, and standards concerning electrical safe work practices and associated worker safety. References to applicable DOE Orders, manuals, procedures, codes, handbooks, regulations and standards are inserted in italics at specific points throughout the manual text and in *Appendix B Definitions and Acronyms*.

3.2.2.9 Research and Development Activities

Section 11 *Research and Development* includes some of the items covered in other sections of this manual. These duplications are considered necessary in order to provide proper emphasis on the special activities that occur in a R&D laboratory.

3.3 Electrical Safety Manual Administration and Management

The Electrical Safety Program for Ames Laboratory shall be the responsibility of the ESC with technical assistance from FES staff. This manual is the responsibility of the Ames Laboratory ESC. FES shall provide direct assistance to the ESC with the management and maintenance of this manual. This document will be reviewed at least every three years.

3.3.1 Authority Having Jurisdiction (AHJ)

In states and municipalities, an official is usually designated as the Authority Having Jurisdiction (AHJ). At Ames Laboratory, the AHJ function is performed by the Ames Laboratory ESC. The ESC/AHJ, with its diverse representation from all areas of Ames Laboratory, does possess the executive ability required for performance of this function and does have thorough knowledge of standard materials and methods used in the installation and maintenance of electrical equipment. The ESC/AHJ is well versed in approved methods of construction and procedures of maintenance relative to safety for persons and property. The ESC/AHJ is knowledgeable through experience or education of the requirements contained in the OSHA standards, the *National Electrical Code (NEC)*, the *Standard for Electrical Safety in the Workplace (NFPA 70E)*, DOE requirements, and other appropriate standards. The ESC/AHJ shall be responsible to interpret codes and regulations and approve equipment, assemblies, or materials. The ESC/AHJ may permit alternate methods where it is assured that equivalent objectives can be achieved by establishing and maintaining effective safety equal to or exceeding established codes and standards.

In DOE, levels of authority exist that also serve the function of a higher level of AHJ and may be the contracting officer or operations manager. This person may choose to delegate their authority to an individual or organization within their control.

At Ames Laboratory, a DOE Contractor, the line of authority shall be established and recognized as starting with the electrical worker (i.e., electrician, electronics technician, researcher, student, etc.) and continuing to the first-line supervisor, activity supervisor, group/section leader, program director/department manager, division director and Laboratory Director.

3.4 Exemptions and Waivers

3.4.1 Exemptions

An exemption is a written release from a mandatory standard and can only be granted by the DOE Assistant Secretary for Environment, Safety, and Health (EH-1). Requests for an exemption shall be submitted for action only by the Ames Laboratory ESC through the DOE field office manager. Each request shall contain, as a minimum, the following information:

- Description of the condition
- Safety standard not being complied with
- Reason why compliance cannot be achieved
- Steps taken to provide equivalent protection
- Statement of whether equivalent safety is provided, and if not, an assessment of the residual risk
- Any proposed corrective action and the schedule for its completion
- Duration of the exemption

EH-1 is responsible for the final determination as to whether the exemption is approved or denied and for notifying the field office manager.

3.4.2 Waivers

If any activity, operation, or process is determined not to be in compliance with advisory standards (but such activity, operation, or process is determined to be safe and necessary) the ESC may internally approve it by requesting a waiver which must be approved by the Ames Laboratory contracting officer. Waivers will be granted for the minimum necessary time, and those of an ongoing nature shall be updated every three years. A central file of active waivers shall be maintained by the ESC. Each waiver shall contain, as a minimum, the following information:

- Description of the condition
- Safety standard requirement not being complied with
- Reason why compliance cannot be achieved
- Steps taken to provide equivalent protection
- Any proposed corrective action and the schedule for its completion

- Duration requested for the waiver

3.5 Ames Laboratory Electrical Safety Committee (ESC)

The purpose, scope and organization of the Ames Laboratory Electrical Safety Committee (ESC) are found in the ESC Charter.

The Ames Laboratory Director, in March of 1993, established a standing ESC to administer an Electrical Safety Program for all of the Laboratory's activities. The ESC will ensure that requirements of the Department of Energy (DOE), Occupational Safety and Health Administration (OSHA), National Fire Protection Association (NFPA), American National Standards Institute (ANSI), Uniform Building Code (UBC), and other applicable state/local codes are addressed.

3.5.1 Purpose

The Ames Laboratory ESC is a standing committee established to develop and implement the Ames Laboratory Electrical Safety Program. The committee is charged with advising the Safety Review Committee (SRC) and the Ames Laboratory Director regarding electrical safety and compliance with DOE and other federal, state, and local regulations. The committee shall be the AHJ.

3.5.2 Responsibilities

The responsibilities of the ESC include:

- Providing Ames Laboratory with a competent technical resource for identifying, recommending resolution of, and communicating electrical safety issues.
- Providing regular communication of activities to the SRC as an essential committee activity.
- Advising the SRC and the Ames Laboratory Director on electrical safety issues as the official AHJ for Ames Laboratory.
- Providing ESC minutes to the Chair of the SRC. (The ESC Chair, or an alternate member, may be asked to attend SRC meetings when required)
- Maintaining the Ames Laboratory Electrical Safety Manual.
- Maintaining an electrical safety training program for Qualified Electrical Workers (QEW) and awareness training for unqualified persons.
- Reviewing the Ames Laboratory Electrical Safety Program every three years or whenever changes have occurred in federal, state or local policies, codes, or standards.
- Enhancing electrical safety by ensuring that appropriate staff reduce risk and mitigate hazards, and by providing root cause analysis reviews of occurrence reports involving electrical accidents e.g., electrical energy distribution, applications in R&D laboratories and other workplaces.
- Identifying the need for and establish new electrical safety initiatives and programs.
- Participating in DOE electrical safety programs such as the Headquarters DOE Electrical Safety Committee.

3.6 Electrical Safety Responsibilities of Others

3.6.1 Chief Research Officer (CRO)/Chief Operations Officer (COO)

The CRO/COO or a designee shall ensure the division possesses the resources for meeting all administrative, design, training, construction, and maintenance requirements of this manual in the operations they manage.

3.6.2 Program Director/Department Manager and/or Person-in-Charge (PIC)

The program director/department manager and/or PIC shall be authorized by the division director/COO to ensure that necessary resources are provided to comply with the electrical safety requirements of this manual. The areas of compliance shall include: practices and procedures; instructions; new employee training; workplace personal protective equipment; standard operating procedures; administrative authority; records; knowledge; tools; and devices.

3.6.3 Group/Section Leader and/or Person-in-Charge (PIC)

The group/section leader and/or PIC shall be authorized by the program director/department manager to operate their units in total compliance with the electrical safety requirements of this manual. Their operating procedures shall include:

Safe Work Practices and Procedures: Establish safe work practices and procedures and ensure they are followed for the employees under his/her direction.

Records: Maintain all required records and reports.

Warnings: Ensure unauthorized persons are prevented from approaching places where work is being performed by using appropriate barricades and/or signs.

Tools and Devices: Ensure that tools or devices used are suitable for the work at hand, and that applicable tools have been inspected and tested as required.

Precautions: Adopt precautions that are within the individual's authority to prevent accidents.

Standard Operating Procedure and Safe Work Permit: Ensure the standard operating procedure (SOP) and the Safe Work Permit for Energized Electrical Work is completed when required in accordance with *Appendix E Work Matrices*.

Responsibilities for Group Activities: The group/section leaders shall:

- Comply with all Laboratory policies and procedures for the purchase and installation of new equipment and for the inspection and installation of equipment built in-house.
- Ensure electrical designs are performed, proper installation is arranged, and necessary documentation is maintained for all the scientific electrical/mechanical systems in their workplace.
- Request assistance from Technical and Administrative Departments as required.
- Maintain a process for new and in-service electrical equipment inspections and acceptance testing in accordance with Section 8, *Acquisition, Fabrication, and Maintenance of Electrical Equipment* and Section 10, *Selection, Inspection, and Testing of Personal Protection and Testing Equipment*.
- Provide assurance that all electrical workers within the group/section are trained for the electrical hazards involved in their assigned activities.

- Assure work involving potentially injurious electrical circuits does not proceed unless all qualified personnel have followed the appropriate policies from this manual, the outlined procedures from the group/section's applicable equipment manuals, and/or the procedures from the Ames Laboratory Environment, Safety, Health and Assurance Program Manual Section 5.12, Lockout/Tagout Program.
- Assure that specifications for equipment include the requirement that the item has been certified by a Nationally Recognized Testing Laboratory (NRTL), or that waivers have been obtained in advance from the ESC.
- Maintain equipment, conductors, and raceways in accordance with documented procedures required by Chapter 8, *Acquisition, Fabrication, and Maintenance of Electrical Equipment*, and Chapter 11, *Research and Development*, Section 11.2.15, *Use of Nationally Recognized Testing Laboratory (NRTL) Tested Equipment*.

Training: Ensure all required training and training documentation referenced in this manual are completed.

Electrical Shock Reporting: The supervisor shall immediately evaluate the employee's condition and provide assistance if needed. Emergency events shall be reported by calling 911. Shut down equipment or remove the hazard immediately and report the event to ESH&A.

3.6.4 Facilities and Engineering Services (FES)

Facilities and Engineering Services (FES) is responsible for the maintenance of Ames Laboratory sites, buildings and utility systems and has sole responsibility for the electrical distribution system and all modifications to buildings. These responsibilities include:

- Modification and maintenance of building supply of electric power to each receptacle;
- Maintenance of the Ames Laboratory standby power service;
- Installation of structurally supported equipment and raceways;
- Penetrating walls and otherwise changing the building structure; and
- Constructing or modifying data communications and telecommunications wiring (interconnecting rooms and/or buildings, but generally not including termination made by Information Systems others).

FES also provides expertise on electronic systems for the entire Laboratory; this includes an acting certified Electrical Safety Inspector. The Inspector shall:

- Provide assistance to group/section leaders, upon request, in the design, installation, and documentation of electrical/mechanical systems and equipment;
- Design, procure, fabricate, install, and maintain electrical safety systems;
- Provide training, in coordination with the ESH&A, to authorized designated group/section members in electrical safety, signal wiring, system wiring, and equipment wiring;
- Install signal cabling external to laboratory spaces including terminating signal devices (installation may include signal cable distribution within the laboratory space when requested);

- Provide direct assistance to the Ames Laboratory ESC with the management and maintenance of this manual;
- Review requisitions for purchase and identify when inspection is required*;*
- Inspect identified items of electrical equipment upon receipt; and
- Establish a process for new and in-service electrical equipment inspections, acceptance testing, and documented maintenance procedures.

3.6.5 Document Control

Document Control (DC) staff tracks the review cycle for the *Ames Laboratory Electrical Safety Manual (46200.001)* to ensure the document is updated at required intervals. DC also posts the manual on the Ames Laboratory website and ensures only the most recent revision is available in the Emergency Operating Records folder on Cybox.

3.6.7 Information Systems

Information Systems (IS) shall be responsible for design, general operation, and support of local area and wide area data communications network infrastructure and associated active components. This involvement includes providing recommendations concerning signal wire routing; determination of the location and number of ports and/or active components required to support a data communication request; coordinating maintenance contracts for network infrastructure active components (for example, routers, bridges, repeaters, network hubs, etc.); and administration of network address assignments. IS reviews and coordinates such activities with the Network requestors, FES, and ESH&A.

3.6.8 Qualified Electrical Worker (QEW)

QEWs need to ensure their own safety. They should not rely upon others for their protection.

Manual Compliance: Workers shall comply with all portions of this manual that apply to their own actions and conduct of operations, including the immediate reporting of unsafe conditions to their first-line supervisor, or activity supervisor. They are also responsible for knowing and following the safe procedures and practices that are specific to their organization and facility.

Unfamiliar Hazards: If workers' duties bring them into the vicinity of equipment where there are unfamiliar hazards, they shall notify their first-line supervisor or activity supervisor and shall not proceed with the work.

3.7 Affected Employee

Affected persons shall consider the real and potential hazards of electrical energy in the workplace as they perform their work functions in proximity to energized or potentially energized electrical parts where the opportunity for inadvertent contact exists. The affected person shall be knowledgeable in those sections of this manual where electrical hazard recognition, safety precautions, and other similar requirements offer information to protect such persons from potential injury due to electrical contact, and/or electrical flash (Appendix B).

3.8 Contractors/Visitors

All contractors and/or visitors shall follow, as a minimum, all the safety regulations contained in this manual, including a qualified person as an escort, when exposed to electrical hazards (Appendix B).

3.9 Ames Laboratory Delegated Representative

The Ames Laboratory Delegated Representative (ALDR) shall ensure those persons/contractors under his/her guidance shall, as a minimum, be apprised of the applicable safety requirements contained in this manual, including a qualified person as an escort, when exposed to electrical hazards (Appendix B).

3.10 Ownership

This manual is owned by the Ames Laboratory Electrical Safety Committee (ESC). The manual is maintained and is issued as a controlled document by FES. Ideas and/or suggestions for improvements or clarification should be forwarded to the ESC Chair. All additions, deletions or changes will be controlled by the ESC.

4.0 ADMINSTRATIVE CONTROL

The division director and/or person-in-charge (PIC) shall ensure that designs for all existing systems, modifications and new construction meet, as a minimum, all safety related requirements of these guidelines, as well as the requirements contained in other applicable standards and procedures mandated by DOE Orders, Ames Laboratory Directives, or governmental codes and laws.

4.1 Supplier (Vendor) Control

The group/section leader, Purchasing & Property Services, and FES in performance of the Ames Laboratory Procurement Operating Practices Manual, shall ensure that all vendor or supplier equipment and systems meet all safety requirements of this manual and applicable mandated and consensus codes and standards, DOE Orders, and Ames Laboratory Directives.

4.2 Construction/Maintenance Control

The group/section leader and/or PIC and ESH&A shall ensure that all construction and/or maintenance projects meet all safety requirements and applicable standards and procedures mandated by DOE Orders, Ames Laboratory directives, and governmental codes and laws.

4.2.1 Contractors

Contractor personnel shall follow the safety procedures contained in this manual, as well as the requirements contained in applicable standards and procedures mandated by DOE, Ames Laboratory requirements, and governmental codes and standards (NFPA 70E). Contractors shall present documentation as validation for meeting these requirements. This documentation shall be presented to the Ames Laboratory contract representative, division director, or the PIC prior to the start of work.

Change in Working Conditions: When the contractor encounters a changing work condition that could place his/her employees at risk with a potential electrical hazard, work shall be stopped, and the appropriate Ames Laboratory representative shall be notified.

Change in Personnel: When contractor employees are replaced or added, these new employees shall be advised of all applicable electrical safety standards for their work location.

4.2.2 Escorting Non-Qualified Personnel

Persons without the appropriate electrical hazards training specified in this manual shall be classified as non-qualified and shall be escorted by a qualified person when necessary. Examples include visitors, non-electrical maintenance employees, supervisors, administrators, potential contractor personnel and equipment suppliers (vendors).

4.2.3 Electrical Systems Requiring Locking

The following installations shall have limited access requiring authorized key entry.

Substations: All substations that have exposed energized parts or exposed potentially energized parts shall be locked.

Switchgear and Equipment Rooms: All switchgear and equipment room location entrances shall be locked.

Energized or Potentially Energized Parts: All other locations that have energized or potentially energized conductors and exposed equipment parts shall be locked.

Potentially Hazardous Situations: All other locations shall be locked where access by unqualified persons and deliberate or inadvertent operation of a switch or control point could potentially cause system failure or create a potentially hazardous situation for other persons or equipment.

Exception: The above installations shall be locked unless work or inspection of area by qualified and/or authorized persons is actively being performed to necessitate the unlocked state.

4.2.4 Lock Classifications

Lockout/Tagout: For personal protection, a lock is required to prevent unintentional operation of a switch or control device. Locks are required to be installed on each lockout/tagout location and shall be color-coded red with a Danger Tag (e.g., Danger Do Not Operate" tag). This lock is to be a controlled lock as defined in the Lockout/Tagout Program.

Operational Lockout: An operating system lock shall be used to prevent unintentional operation of hazardous electrical switch equipment. Lock shall not be red and a notice tag is recommended with the name of the person who applied it. This lock is controlled via the Lockout/Tagout Program.

Preferred Lock System: In the interest of overall employee safety, a one lock/one key system offers the highest degree of safety in any locking situation.

4.2.5 Equipment Access Interlock for Engineered Safety Systems

These systems offer a high degree of personal safety and should be utilized in all design considerations. Generally, the interlock system shall not be bypassed while energized, or otherwise rendered inoperative.

Temporary Bypassing: Only a QEW, following the requirements in the Safe Work Practices section of this manual, and with approval from the first-line supervisor or activity supervisor, may defeat an electrical safety interlock, and then only temporarily while he/she is working on the equipment. The interlock system shall be returned to its operable condition when this work is completed, usually during the same shift.

Approval and Documentation: If the interlock system must be temporarily bypassed for instances such as testing, specific procedures must be followed to ensure personnel safety and knowledgeable supervisory approval. Upon completion of the testing, the interlock system shall be restored to full operable status and these activities recorded in the equipment log book.

4.2.6 Electrical System(s) Safety for Operations

It is essential that general utility power switching and clearance procedures for and between Iowa State University and Ames Laboratory are well understood and documented by all participating parties. NFPA 70E requirements shall be followed. Any electrical work done by Iowa State University for Ames Laboratory will require a mutually agreed upon written description of the activity with the safety precautions that will be taken. At a minimum, arc flash and shock hazards (in accordance with NFPA 70E) must be addressed.

4.2.7 Training and Documentation Requirements

The division director/COO, program director/department manager, group/section leader, and PIC shall assure that all required training and documentation referenced in this manual are completed.

4.2.8 Lockout/Tagout Procedure

The following are the established procedures for application of energy control and lockout/tagout.

Action

Step 1 Before proceeding with any equipment shutdown, a survey will be made to locate and identify all energy isolating devices feeding the equipment (i.e., electrical circuit breakers, shut-off valves, electrical disconnect switches, etc.).

Step 2 Once the survey is complete, the authorized personnel will notify all affected personnel, including the area supervisor that a shutdown of the equipment or machine will occur.

Step 3 Following notification, the equipment or machine, if operational, will be shut down by normal stopping procedure (i.e., depress stop button, open toggle switch, turn switch off, etc.).

Step 4 Once turned off, the energy-isolating device(s) (i.e., circuit breaker, disconnect switch, etc.) will be operated in such a manner that the machine or equipment will be isolated from the energy source (electrical, mechanical, hydraulic, pneumatic, chemical, thermal, etc.).

Step 5 The energy-isolating device is then "locked out" by applying the padlock (red) and Lockout Tag to the device.

Note: If a machine or equipment cannot be locked out by conventional means call ESH&A. Tagout can be used for isolated instances. For tagout to be considered, implementation of additional safety measures shall be completed (i.e., the removal of an isolating element, blocking of a controlling switch, opening an extra disconnecting to reduce the likelihood of inadvertent energization).

Step 6 A tag will be filled out by each authorized person indicating the person's name, and date of the lockout.

Step 7 Once the energy-isolating device has been locked out and tagged, all potentially hazardous sources or residual energy will be purged or dissipated (i.e., grounding, discharging capacitors, etc.)

Note: Every person involved with the service or maintenance of the locked out equipment will place their assigned padlock to every lockout device in such manner that if all other padlocks were removed, the person would still have their padlock assuring that every source of energy is still "locked out". No personnel may affix the lockout/tagout device of another person.

Step 8 The following are to be performed to ensure machinery/equipment is in a zero energy state:

- Remove conductive apparel.
- Wear the appropriate personal protective equipment.
- Perform testing using an approved category III or IV multi-meter.

Measuring technique:

- Verify meter operates properly on a known power source within the same voltage range.
- Ground one terminal of meter.
- Connect to one phase, measure to ground, measure other phases to ground.
- Remove ground, measure phase to phase for all phases.
- If possible, use one hand at a time.
- When complete, verify meter operates properly on a known power source within the same voltage range.
- Try to start the equipment (return the controls to the neutral position when finished).
- Stop work if unanticipated conditions exist.

Note:

- Attach a "ground stick" of sufficient size to handle any possible fault current to all three phases of stored electrical equipment.
- Blocking shall be performed on hydraulic equipment such as presses which must be maintained in a stored hazardous potential state.

Step 9 Maintenance or servicing of the machine or equipment may now be performed.

4.2.9 Reactivation of Energy Source

The following are the established procedures for reactivation of an energy source that has been locked and tagged:

Action

Step 1 When the maintenance and/or service are completed, the work area is to be inspected to ensure that all affected personnel are safely positioned and/or removed. In addition, remove all nonessential items from the equipment.

Step 2 The authorized person who applied the lockout/tagout shall then remove the lockout and tag from the energy-isolating device.

Step 3 When the authorized person who applied the lockout/tagout device is not available to remove it, that device may be removed provided:

- Verification by the supervisor, group leader or department manager that the authorized person who applied the device is not in the facility.
- All efforts to contact the authorized person to inform them that their lockout device has been removed.
- The authorized employee, if contacted and cannot return, is asked relevant questions about the status of the equipment or machinery locked out.
- The authorized employee has all relevant information about the lockout and the equipment condition before work resumes.

Note: If the employee who applied their lockout device is not available to remove the lockout/tagout, the device may only be removed by the supervisor, group leader or manager, in accordance with step 3 above.

4.2.10 Shift and/or Personnel Changes

If work on a piece of equipment or machinery that is locked out carries over to the next shift, the authorized personnel may remove their lockout device, provided that the next authorized personnel applies their lockout device at the same time the previous authorized personnel removes their lock device.

4.2.11 Testing of Machinery, Equipment and/or Trouble-Shooting

When machinery and/or equipment must be energized before service work is completed (i.e., testing, troubleshooting, checking motor rotation, electrical calibration, etc.) the following procedure shall be used:

Action

Step 1 Clear the machine and/or equipment of nonessential items.

Step 2 Safely clear personnel from the machine area.

Step 3 Remove lockout / tagout devices from energy isolating equipment.

Step 4 Ensure PPE required per OSHA Safety Related Work Practices is utilized (i.e., insulating gloves, mats, sleeves, safety glasses, etc.).

Step 5 Energize and proceed with the test.

Step 6 De-energize all systems and reapply lockout / tagout devices to the energy isolating devices to proceed with maintenance.

5.0 TRAINING REQUIREMENTS FOR ELECTRICAL SAFETY

5.1 Background

In order to protect employees from the potential hazards of electrical energy used throughout the Laboratory, the Electrical Safety Committee (ESC) has developed an Electrical Safety Training program. The Department of Energy and OSHA have mandated these training requirements. Experience has shown that workers who have been thoroughly trained are less likely to be injured by electrical accidents. All employees shall possess a basic knowledge of electrical theory, have experience in electrical work, and be familiar with standard work practices before being considered for QEW training.

5.1.1 Conditions Requiring Electrical Safety Training

All employees who are exposed to electrical hazards (e.g., face the risk of electrical shock or injury) above 50 volts or high current (above 10 amps) and supervisors who oversee electrical work shall be trained and obtain the status of qualified electrical worker (QEW). An employee must be designated as a QEW in order to perform the following activities:

- Live (energized) work at ≥ 50 volts
- Live (energized) work with high current systems
- Troubleshoot, build and/or repair apparatus, bypass interlocks or inhibit safety systems
- Verify that a circuit is de-energized before de-energized work is started; unless a QEW has verified that a circuit is de-energized it must be treated as live (energized) work

Line managers at or above the group leader level who do not supervise QEWs are not required to obtain QEW status.

5.1.2 Required Training Modules

Researcher Electrical Safety Training

This module is for scientific staff who operate, adjust, and load samples into research electrical equipment. All parts are assumed to be properly guarded and no exposure to live parts above 50 volts or high current is allowed.

The Institutional Special Employee Training (SET) modules listed below are designed for **Qualified Electrical Workers (QEWs)**.

- **Qualified Electrical Worker/Retraining** is required for all employees and their immediate supervisors who are exposed to electrical hazards at 600 volts or less when performing any of the three actions listed above in Section 5.1.1. These employees must have a basic knowledge of electrical theory, have experience in electrical work, and be familiar with standard work practices before being considered for QEW training. This module is a prerequisite for all additional electrical safety modules and retraining is required every three years.

- **High Voltage Electrical Safety/Retraining** is required for employees and their immediate supervisor who are exposed to electrical hazards greater than 600 volts when performing any of the three actions listed above in Section 3.1.1. Retraining is required every three years.

- **NFPA 70E Training** is required for full time electrical workers who may be exposed to arc/flash hazards in their work activities. Retraining is required every three years.

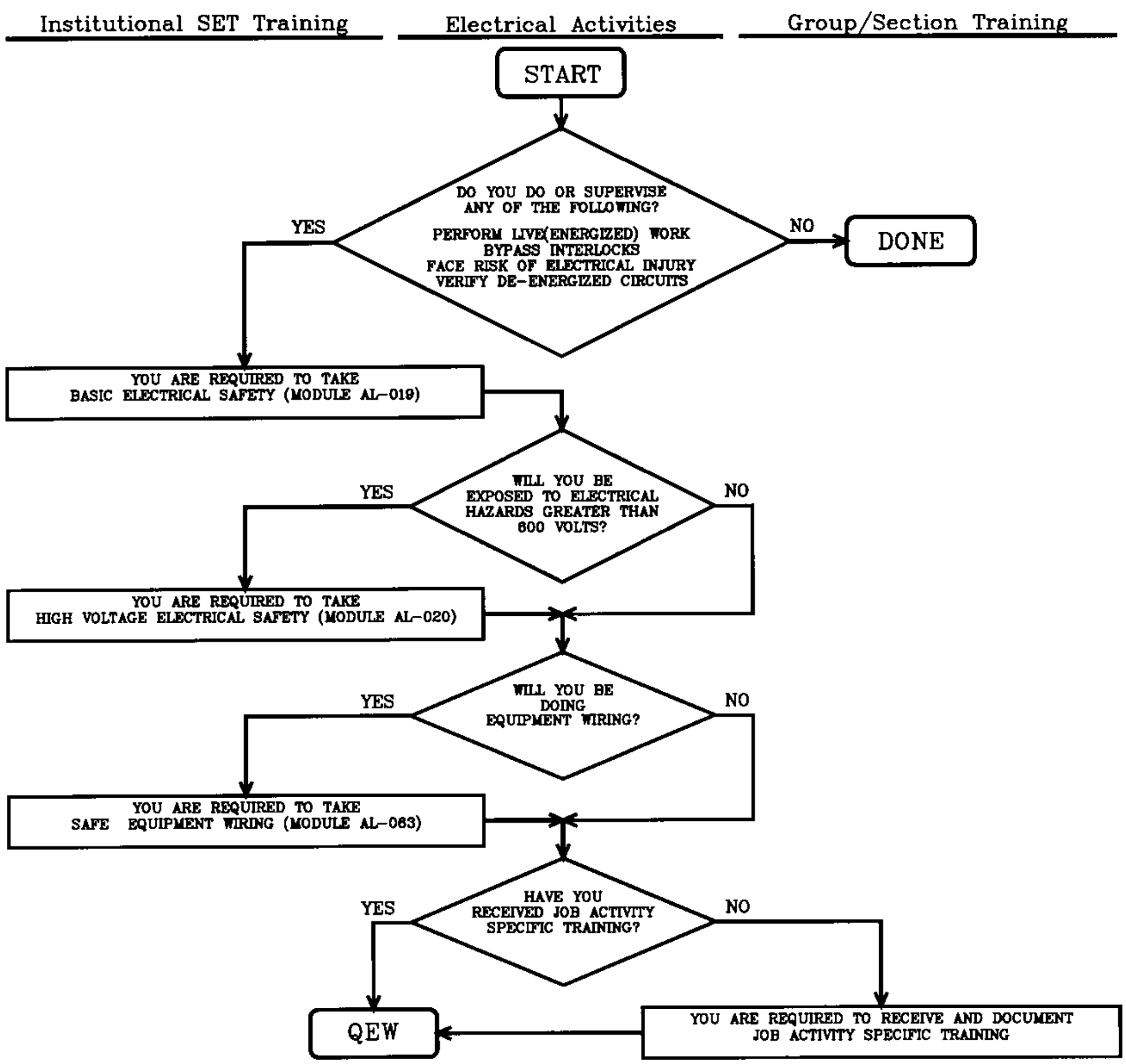
- **Safe Equipment Wiring/Retraining** is required for workers and their immediate supervisors who will be performing equipment wiring within their work areas. (see definition of equipment power wiring). This module is required for modification or construction of electrical equipment operating at over 50 volts, or at high current, and is recommended for electrical work under 50 volts. Retraining is required every three years.

- **Hazard Awareness for Custodians/Plant Protection**
  All Custodians and Plant Protection personnel receive this awareness training to inform them of the electrical hazards they may encounter on the job and so they are qualified to change light bulbs and reset a tripped circuit breaker (120Vac).

In addition to the Institutional SET modules listed above, every employee must receive documented activity-specific training provided at the group/section level for their job activity or the equipment that they will be installing, operating, maintaining, and/or repairing.

The QEW training process is illustrated in Figure 5.1.

Figure 5.1 Qualified Electrical Worker (QEW) Training Process



5.1.3 Suggested/Elective Training Modules

In accordance with *29 CFR 1910 Subpart S, electrical paragraph 1910.332*, employees who are not qualified persons shall also be trained in and familiar with any electrically related safety practices which are necessary for their safety. Therefore, all the SET modules listed in Sections 3.1.2 and 3.1.3 should be given to unqualified persons when requested for awareness purposes without retraining requirements. The SET modules listed below are not required for QEWs but are suggested when appropriate.

- **Small Signal and ADP Wiring** is designed for employees working with small signals (i.e., small voltages and currents) and automated data processing (ADP) in a research lab environment.

- CPR training and First Aid certification are available either through Ames Laboratory or ISU for any interested worker. These courses are elective and are recommended when appropriate.

5.2 Training Requirements Policy

Group/section leaders shall ensure that their employees meet all training requirements for QEW relative to job activities. Group/section leaders shall:

- Follow the qualification process for all their employees (see Section 5.2.1);
- Provide activity-specific training;
- Request institutional electrical safety training session when necessary;
- Limit group/section electrical work to that for which their employees have been qualified; and
- Ensure that all of their QEW employees are retrained/requalified as required.

5.2.1 Qualification Process

5.2.1.1 Training

All employees who are exposed to electrical hazards (e.g., face the risk of electrical shock or injury) and supervisors who oversee electrical work shall be trained and obtain the status of QEW. The level of training shall be determined by the hazards they will encounter in the workplace. The qualification process will consist of:

- Institutional SET modules;
- Activity-specific training;
- Coordination and record keeping by ESH&A and the Training office;
- Granting of QEW status by Ames Laboratory; and
- Limits on electrical work performed by group/section QEWs as discussed below:
  - Institutional SET modules shall be coordinated by the Training department.
  - Activity-specific training shall be provided by the group/section leader or designee. This training may be classroom or on-the-job training and shall cover the specific hazards of the employees' work and workplace. The group/section leader shall complete and submit the Qualified Electrical Worker Authorization Form sent to all staff members after they have registered for the electrical safety training modules. This form shall denote all actions the employee will normally perform to assure the appropriate level of QEW is obtained.
  - The Training department will maintain records of completion of Institutional SET modules and QEW sign-off records.
  - Ames Laboratory via the ESC and ESH&A allows the designation of the appropriate status of QEW to the individual employee for a period of up to three (3) years. The record of this grant (date, QEW, employee name, etc.) will be maintained by Training, utilizing the Qualified Electrical Worker Authorization Form.

- Each group/section leader with QEW-rated employees shall limit their electrical work to that for which they have been qualified. All group/section leaders shall review annually the status of their QEW employees relative to job activity changes, new activities, etc.

5.2.2 Institutional Electrical Safety Training

General Employee Training for New Employees: General Employee Training (GET) includes information designed to provide all employees with electrical safety awareness. The electrical safety portion of GET reviews the electrical hazards commonly found in the workplace. Previous electrical training is not required. GET does not imply electrical qualification. Some employees may require additional electrical safety training. Retraining is not required for this course.

Qualified Electrical Worker Training (600 volts or less): This mandatory training module is required for electrical work at or below 600 volts. Participants of this training module should possess a basic knowledge of electrical theory and have experience in electrical work. Training will cover safe work practices, test equipment and tools, safety equipment, grounding, applicable regulations, electrical lockout/tagout, and other safety-related subjects.

High Voltage Electrical Safety Training (greater than 600 volts): This mandatory training module is required for electrical work at greater than 600 volts. Due to the inherent dangers involved with high voltage, safe work practices are stressed. Special tools, test equipment, safety equipment, work matrices, and other applicable subjects will be covered. *Qualified Electrical Worker Training* is a prerequisite.

Safe Equipment Wiring Training: This mandatory training module is required to perform equipment wiring at 50 volts or greater, or at high current, and is recommended for equipment wiring below 50 volts. Safety aspects of equipment wiring will be addressed. Code requirements, proper techniques and materials, Ames Laboratory policies, electrical noise reduction, and other electrical safety practices will be addressed. *Qualified Electrical Worker Training* is required as a prerequisite. *High Voltage Electrical Safety* is a prerequisite when appropriate.

Small Signal & ADP Wiring Training: This elective training module covers working with small signal and automated data processing (ADP) wiring in the research lab environment. Safety, Ames Laboratory policies, industry standards, and improving research data collection will be discussed. Materials and techniques will be reviewed.

Researcher Electrical Safety Training: This module is for scientific staff who operate, adjust, and load samples into research electrical equipment. All parts are assumed to be properly guarded and no exposure to live parts above 50 volts or high current is allowed.

NFPA 70E Training: This training is required for full time electrical workers who may be exposed to arc/flash hazards in their work activities.

Hazard Awareness for Custodians/Plant Protection: All custodians and Plant Protection personnel receive this awareness training to inform them of electrical hazards they may encounter on the job.

5.2.3 Institutional Electrical Safety Retraining

All QEW-rated employees shall be retrained and requalified as a QEW every three years or more frequently if there have been substantial changes to their job activities or to OSHA, DOE Orders, or other standards or codes covering electrical safety.

6.0 SAFE WORK PRACTICES

6.1 Background

Safe work practices begin with knowing the full extent of the job or activity to be undertaken before beginning the work. Assuming an electrical line is de-energized or grounded, or using the incorrect tool or method, may result in severe personal injury and damage to valuable equipment. Know the project or problem well before beginning modifications or repairs.

6.2 Safe Work Practices Policy

Safe electrical work practices shall be used to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts when work is performed near or on equipment or circuits which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards.

6.2.1 Pre-work Briefing

Before any work on electrical equipment begins, all people involved shall be briefed by the group/section leader, PIC, activity supervisor, or first-line supervisor on the safety concerns and precautions regarding the assignments. Whenever work conditions or methods change that could potentially compromise personnel safety, additional briefings shall be held.

6.2.2 Pre-work Briefing Waiver

For those electrical work operations which are repetitive in exact detail and have up-to-date standard operating procedures (SOPs) and/or the Ames Laboratory Safe Work Permit for Energized Electrical Work Form available at the work site, the formal pre-work briefings may be waived upon approval of the group/section leader or PIC.

6.2.3 Basic Rules

Status of electrical equipment and/or lines:

Equipment Status: Electrical equipment and feeders shall be considered energized until tested or otherwise determined by a QEW to be de-energized and grounded, when required.

Direct Current Systems: Rules and guidelines for direct current (DC) systems are the same as those which apply to alternating current (AC) systems except where noted.

6.2.4 Additional Rules for High Voltage Equipment and Systems

Verification of de-energized conditions shall be made by a QEW before any work is performed on or near non-insulated high voltage lines and/or exposed live parts.

Verification of Energized/De-energized Status: A QEW shall verify that no energized condition exists as a result of inadvertently induced voltage and/or back feed.

Test Equipment Inspection: Test equipment shall be checked for proper operation immediately before and immediately after this test.

6.2.5 Exposed and Energized Parts

It is the general policy of Ames Laboratory that **NO** maintenance or installation work is to be performed on conductors and/or exposed equipment parts while they are energized. If energized (live) electrical work is being conducted, the Ames Laboratory Safe Work Permit for Energized Electrical Work form shall be required.

6.2.5.1 Voltage 600 Volts or Less

Specific electrical safety work practices are required when working in proximity to exposed and energized parts in electrical motor control centers (MCC), distribution center panels, and associated lines and field devices. The equipment and systems covered by these practices includes that which operates at 600 volts or less.

6.2.5.2 De-energize or Insulate/Isolate

Before beginning any construction or maintenance work (other than electrical servicing activities covered below) which place the worker(s) in proximity to exposed energized electrical parts, the MCC, distribution center, line or field device shall be totally de-energized or the area of work shall be isolated and insulated. The decision to isolate and insulate instead of de-energize must be made by a QEW. Live parts that operate at less than 50 volts to ground need not be de-energized if there will be no increased exposure to electrical burns or explosions due to electric arcs.

6.2.5.3 Detailed Plan

As part of the job instructions (pre-work briefing) related to those tasks covered in Section 6.2.5.1, an activity supervisor or first-line supervisor of a QEW will review and discuss the specific hazards involved with the worker(s) who will perform the task(s). A decision to isolate/insulate instead of de-energize will be discussed, and the methods of isolation and insulation to be used shall be detailed.

Electrical servicing (maintenance) activities which require electrical MCCs, distribution centers or lines, or field devices to be energized will require special precautions by the worker performing these activities. Activities covered by this practice may include:

- Preventive maintenance observations and meter checks;
- System tuning;
- Trouble-shooting;
- Routine fuse replacement; and
- Resetting device overloads.

6.2.5.4 Personal Protective Equipment (PPE)

When activities will place the worker in proximity to exposed energized electrical parts, appropriate PPE shall be utilized. The supervisor or qualified person shall approve PPE selection. Such PPE may include:

- Safety glasses (see Section 10.2.2.2);
- Face shields (see Section 10.2.2.2);
- Insulated gloves (see Section 10.2.1) and
- Arc/flash clothing. [see NFPA 70E – Table 130.7(C)(9)(a)]

6.2.5.5 Tool Selection

The supervisor or qualified person shall approve all tools used in conjunction with these approved activities. All tools shall be insulated and of an approved design.

6.2.5.6 Special Situations

There may be special situations in the Ames Laboratory environment which require the replacement of components in equipment in an energized state. If this situation occurs, the guidelines of Section 6.2.5 shall be followed. In addition, a Safe Work Permit for Energized Electrical Work form shall be required.

Justification of Need:

Live parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works on or near them unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Energized parts that operate at less than 50 volts to ground shall not be required to be de-energized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

Fine Point Note (FPN) No. 1: Examples of increased or additional hazards include, but are not limited to, interruption of life support equipment, deactivation of emergency alarm systems, and shutdown of hazardous location ventilation equipment.

FPN No. 2: Examples of work that might be performed on or near exposed energized electrical conductors or circuit parts because of infeasibility due to equipment design or operational limitations include performing diagnostics and testing (e.g., start-up or troubleshooting) of electric circuits that can only be performed with the circuit energized and work on circuits that form an integral part of a continuous process that would otherwise need to be completely shut down in order to permit work on one circuit or piece of equipment.

FPN No. 3: For voltages of less than 50 volts, the decision to de-energize should include consideration of the capacity of the source and any overcurrent protection between the energy source and the worker.

6.2.6 High Voltage (greater than 600 volts)

It is the general policy of Ames Laboratory that **NO** maintenance or installation work is to be performed on high voltage conductors and/or exposed equipment parts while they are energized.

Insulation/Isolation: When a QEW must work on energized lines or parts, they shall insulate and/or isolate exposed energized parts. Protective shields, protective barriers, or insulating materials shall be used to protect each employee from shock, burns, or other electrically related injuries while that employee is working near exposed energized parts which might be accidentally contacted or where dangerous electric heating or arcing might occur. When normally enclosed live parts are exposed for maintenance or repair, they shall be guarded to protect unqualified persons from contact with the live parts. Only QEWs qualified in high voltage work shall perform work on high voltage conductors and/or equipment.

Exceptions for Live High Voltage Work: Any exceptions to this policy shall require the approval of the group leader/department manager, ESC (designee), and CRO/COO utilizing the Safe Work Permit for Energized Electrical Work form.

Exception for Live-Line Work: A QEW qualified in live-line techniques working under the safety conditions described by this manual and current regulations/consensus standards shall be utilized for high voltage live-line work when isolation is not feasible.

6.2.7 Safe Work Zone

Working space around electrical equipment shall be maintained.

6.2.7.1 The Safe Zone

Identification of the Area: In some instances, it is necessary to appropriately barricade, provide signage, or otherwise identify a work area as containing high or low voltage electrical hazards not normally encountered during routine maintenance of the equipment and/or conductors located therein. By appropriately identifying the area, persons are given a higher degree of hazard awareness.

Safe Work Zone: The safe work zone is that area outside the barricaded area, or that area outside the boundary.

6.2.7.2 Areas Accessible to Qualified Electrical Worker

(area inside the barricade or inside the prohibited approach boundary)

Abnormally Exposed Parts: If the work exposes energized parts which are normally protected, danger signs shall be displayed, and suitable barricades shall be erected to prevent unqualified people from entering the area.

Size of Safe Work Zone: When determining the size of the safe work zone, consideration of the type and size of conductive materials and equipment to be used in the area must be made. See Section 8.2.3.6, Approach Boundaries

6.2.7.3 Areas Accessible to Vehicular Traffic and Non-Qualified Persons

When activities being performed on high or low voltage electrical equipment could compromise the safety of adjacent vehicles and pedestrians, appropriate warning signs and/or barricades shall be utilized.

6.2.7.4 Demarcation of Safe Zone and Hazards

Barricades: Electrical hazard barricade tape/rope is intended to be used only as a temporary hazard warning provision. Temporary may be defined as any work assignment where there is an active effort to complete a permanent installation and employee safety is not compromised. The recommended color of electrical hazard barricade tape and rope is YELLOW or YELLOW and BLACK.

Signage: The electrical safety program shall include the use of appropriate signs when required.

Hazard Information: Signs are essential to convey information regarding a potential electrical hazard. Signs may also convey information regarding operation and/or maintenance instructions.

Use of Other References: Specific references listed within this manual should be used to determine the requirements for Ames Laboratory.

Signage Requirements: The following information shall be considered for signage requirements.

- The sign shall be made of a durable material consistent with the anticipated environmental conditions and the expected length of exposure.
- The color and shape of the sign shall be consistent with the requirements of regulatory and consensus standards.
- Lettering shall be prominent and highly visible. Visibility in darkened, minimal light situations shall be considered.
- It is recommended that internationally accepted symbols be used as much as is practical.

Sign Locations: As a minimum, signs shall be placed at the following locations:

- On all doors, gates, fences for substations, doors to switchgear rooms, or other similar compartments where potentially energized exposed electrical parts are located;
- On all transmission and/or distribution structures where worker or public presence may be expected;
- In the case of multi-support structures, signs shall be located on each supporting member;
- At roadways where horizontal or vertical clearance from energized or potentially energized sources is minimal for the expected equipment/vehicle travel;
- At all electrical equipment installations where physical distance requirements for persons, and/or handling of conductive material, or equipment or vehicle operations cannot be met or are marginal;

- Where inadvertent electrical contact is possible, and can reasonably be anticipated; and
- At all electrical equipment locations where a potential back feed is possible and such information is essential for the safe operation of the equipment and personnel safety.

6.2.7.5 Illumination

Employees may not enter spaces containing exposed energized parts unless sufficient illumination is provided to perform the work safely.

Illumination for Non-Testing Electrical Work: When observations and/or work not requiring testing is to be performed in spaces outlined in Section 4.2.5.1, a minimum illumination level of 20 foot-candles must be maintained either by permanently installed lighting systems, temporary supplemental lighting systems, or a combination source.

Illumination for Testing Electrical Work: When testing is to be performed in spaces outlined in Section 6.2.5.1, a minimum illumination level of 100 foot-candles must be maintained either by permanently installed lighting systems, temporary supplemental lighting systems, or a combination of sources.

6.2.7.6 Confined or Enclosed Work Spaces

When working in a confined or enclosed space which contains exposed energized parts, the worker shall follow the provisions of Section 4.2.5 and the Personal Protective Equipment and Confined Space Entry in section five of the *Ames Laboratory Environment, Safety, Health and Assurance Program Manual*.

6.2.8 Lockout/Tagout

All work performed by the Ames Laboratory or subcontractor personnel shall follow the Machine Guarding, Electrical Safety and Electrical Related Work Practices and the Lockout/Tagout sections of the Ames Laboratory Environment, Safety, Health and Assurance Program Manual.

6.2.9 Safe Grounding Techniques

Before doing any work on de-energized lines or equipment, the lines or equipment shall be tested for voltage and be properly grounded in accordance with the policy described in the grounding section of this manual.

6.2.10 Servicing Electrical Equipment and Systems

All work should be performed with equipment and/or systems in a de-energized state as outlined in Section 6.2.5.

Personal Protective Equipment (PPE): When equipment and/or systems must be energized to facilitate the trouble-shooting process, the worker shall insulate/isolate and/or wear appropriate protective equipment as directed in other chapters of this manual. (Refer to Selection, Inspection, and Testing of Personal Protection and Testing Equipment section of this manual.)

Equipment Rating: All test equipment used in the troubleshooting activity shall be rated for the service under test.

Resetting Overload Device: No over-current device, overload, or fuse shall be reset or replaced until the cause of the overload trip has been determined and corrected. The repetitive manual reclosing of circuit breakers, overload devices and replacing fuses is not permitted. If breakers are to be used as switches (i.e., lighting), they must be rated/approved for such usage and labeled SWD (switch rated device).

Proper Use of Load Interrupters: Only devices designed with load-interrupting capabilities shall be used as a disconnecting means for energized circuits.

6.2.11 Safety Interlocks

Only a QEW, following the requirements in this chapter and with approval from the group/section leader or PIC, may defeat an electrical safety interlock, and then only temporarily while he or she is working on the equipment. The interlock system shall be returned to its operable condition when this work is completed.

Interlock Reset: Interlock devices/systems shall be returned to operation upon completion of testing.

6.2.12 Modifications/Installations

Modifications to existing equipment and systems should be performed in a de-energized state.

Personal Protective Equipment (PPE) for Energized Work: When de-energization is not feasible, the worker must isolate/insulate themselves from energized parts (refer to Section 12.2).

Safe-Use Documentation: Any equipment that was initially approved by an NRTL, and has been subsequently modified, shall be deemed to have avoided certification. In this case, documentation (acceptable to the ESC) shall exist that reasonably demonstrates the equipment is safe to approach and operate.

6.2.13 Storage Batteries and Battery Banks

Rechargeable type storage batteries require specific practices to minimize personal risk while servicing and/or inspecting. (See the *Requirements for Specific R&D Equipment* and *Requirements for Specific Building Equipment* sections of this manual.)

Tools: Only insulated hand tools shall be used when working on or near battery terminals.

Personal Protective Equipment (PPE): Electrolytes shall only be handled by personnel properly protected by eye protection (goggles or face shields), long sleeves and rubber gloves (refer to Section 10.2).

Exhaust Systems: Exhaust systems shall be maintained operable to minimize the risk of hazardous and toxic fume(s) accumulation.

Safety Shower/Wash: Facilities for quick drenching of the eyes and body shall be available.

Other Water Facilities: Facilities for flushing and neutralizing spilled electrolytes shall be provided.

6.2.14 Auxiliary Systems

In some cases auxiliary equipment, such as lighting fixtures, alarm systems, public address systems, or communication and computer cable, is placed on support structures used for high voltage non-insulated electrical transmission and distribution systems. In order to reduce the hazard of contact with non-insulated high voltage conductors while servicing these systems, it is strongly recommended that these auxiliary systems follow the procedures outlined below.

Relocation: Consideration shall be given to relocating the equipment in question.

Safe Servicing Methods: Alternate safe work practices for servicing such equipment shall be implemented, such as de-energizing the high voltage part, and/or wearing appropriate personal protective safety equipment for working in proximity to high voltage energized parts.

6.2.15 Modifications/Installations

Modifications of high voltage systems will always be performed with the equipment/system de-energized and secured.

6.2.16 Underground Systems

Underground services may include manholes, vaults, direct burial cable systems, and buried raceways.

Qualified Electricians: Only qualified electricians shall perform maintenance work and/or service work on Ames Laboratory systems which could be energized.

Proper Procedures: Before beginning work on the power system, the appropriate switching procedures shall be obtained from the responsible engineer.

Confined Space: Before entering any confined space, all safety requirements for the Confined Space Entry Program section of the Environment, Safety, Health and Assurance Program Manual shall be followed.

Barricades: When manholes or vaults are open, the opening shall be protected with suitable barricades, and during the hours of darkness or poor visibility, with proper warning lighting (refer to Section 6.2.7.4).

Safe Grounding Techniques: Before doing any work on de-energized underground lines and equipment, the elements of Section 6.2.10 of this manual shall be reviewed.

6.2.17 Construction Locations

The following procedures shall be used when working in construction areas.

Ground Fault Circuit Interrupters (GFCI): Branch Circuits - Ground Fault Circuit Interrupters (GFCI) are to be used on all 120 volts, AC single-phase 15 and 20 ampere receptacles which are not part of the permanent wiring of the installation or location.

Ground Fault Circuit Interrupters Exception: Receptacles on a two-wire, single-phase portable generator rated not more than 50 kW, where the circuit conductors of the generator are insulated from the generator frame and all other grounded surfaces, need not be protected with ground-fault circuit interrupters.

Insulated Gloves: Employees using jackhammers, bars or other hand tools in a work area where underground electrical power lines are located shall be provided with and instructed to use insulating protective gloves (refer to Section 10.2).

6.2.18 Portable Generators

Portable or vehicle mounted generators rated 5 kV or less, using a single phase 2 wire generator circuit insulated from all grounded surfaces and the generator frame, need not be grounded or protected by ground fault circuit interrupters.

GFCI Requirements: Portable or vehicle mounted generators not meeting the provisions of Section 6.2.17.2 shall be equipped with GFCIs as covered in Section 6.2.17.

7.0 GROUNDING

7.1 Background

This section covers general rules for the grounding and bonding of electrical installations. The ultimate goal of system protection is to prevent ground faults from occurring by using proper design, installation, operation, and maintenance of electrical equipment and circuit systems. However, there is always the threat of ground faults because of accidents or insulation failure in electrical systems. Therefore, proper protection of such systems by the use of grounding is required to safely clear the phase-to-ground faults that can occur (also see Section 6.2.10).

Qualified workers must clearly understand the definition and intent of the following components of a grounding system that are discussed in this chapter:

- Bonding conductor;
- Grounding conductor (green); and
- Grounded conductor (white-neutral).

7.2 Grounding Policy

All electrical equipment in Ames Laboratory shall be properly grounded unless listed as double insulated or battery powered with no hazardous voltages generated.

7.2.1 Circuit and System Grounding

Circuit and system grounding in the Laboratory consists of connecting the equipment grounding conductor and bonding jumpers to a common ground as provided by FES. The purpose of circuit and system grounding is to:

- Limit excessive voltage from lightning, line surges, and crossovers with higher voltage lines;

- Keep conductor enclosures and noncurrent-carrying metal enclosures and equipment at zero potential relative to ground; and
- Facilitate the opening of overcurrent protection devices in case of insulation failures or short circuits.

7.2.2 Bonding Conductor

The bonding conductor is the grounding conductor external to an array of electrical devices that ensures proper grounding of those devices.

Selecting Bonding Conductors: Extreme caution shall be taken to ensure that the equipment bonding jumper is correctly sized because it must be rated for the fault current trip setting of the overcurrent protective devices. The bonding conductor(s) shall provide the following:

- Permanent connection;
- Positive continuity at all times; and
- Ampacity to conduct fault currents

7.2.3 Grounding Conductor (Green)

The grounding conductor has green insulation and carries the fault currents to the receptacle. The grounding conductor shall be integral with the electrical power supplied to the equipment.

- Connection of the grounding conductor (green) to the grounded conductor (white/neutral) is prohibited except at the ground rod.
- The grounding conductor (green) is primarily the responsibility of the FES to install to all outlets and disconnect devices that serve the user's equipment.
- The grounding conductor (green) shall meet NEC requirements for insulation and current carrying capacity and meet other applicable codes.

7.2.4 Grounded Conductor (White/Neutral)

The grounded conductor (also called neutral) has white insulation and carries the normal phase to ground circuit currents.

- Connection of the grounded conductor (white/neutral) to the grounding conductor (green) is prohibited.
- The grounded conductor (white/neutral) shall not be bonded to any electrical device.
- The grounded conductor (white/neutral) shall be installed by the FES to all outlets and disconnect devices that serve the user's equipment.
- The grounded conductor (white/neutral) shall meet NEC requirements for sizing and meet other applicable codes.

7.2.5 Building Services

The FES shall utilize the details of Chapter 4, *Grounding* found in the *DOE Handbook, Electrical Safety, No. DOE-HDBK-1092-2013, December 2013*, NEC, and other applicable codes when installing the main/primary building electrical service.

7.2.6 Ground Rod (Grid)

There shall be only one grounding electrode (grid) per building service. Attached to that one electrode shall be the following:

- Building service grounding conductor (green);

- Building service grounded conductor (white/neutral); and
- The isolated grounding conductors when necessary.

Lightning Rod: Lightning protection shall have its own grounding electrode system meeting lightning protection standards.

Radio Frequency (RF) Ground: The requirements for high frequency (RF) grounds will be reviewed by the ESC.

7.2.7 Ground Fault Protection (GFP) of Equipment

An increased degree of protection in solidly grounded systems can be achieved by providing ground fault protection (GFP) that will shunt trip circuit protective devices when user-selected levels of ground fault or leakage current flow are detected in electrical circuits.

7.2.8 Personnel Safety Grounds

Personnel working on or in close proximity to de-energized lines or conductors in electrical equipment shall be protected against shock hazards and flash burns that could occur if the circuit were inadvertently re-energized. Properly installed safety grounds can alleviate such hazards to personnel servicing, repairing, and working on such systems.

7.2.9 Safe Grounding Methods

Before doing any work on de-energized lines or equipment, the lines or equipment shall be tested for voltage and be properly grounded.

Inspection: Before installing grounds, the grounding equipment shall be visually inspected to confirm equipment integrity.

Current Capacity: Safety ground sets shall be capable of conducting the maximum ground fault current which could flow at the point of grounding for the time necessary to clear the fault. This equipment shall have a current carrying capacity equal to or greater than 2/0 AWG copper cable.

Grounding Location: If the installation of protective grounding equipment at the work location is not feasible, grounding devices shall be installed on each side of the work, as close to the work as possible.

Isolated Equipment: If the line or equipment can be isolated at the work location, both sides of the isolated device shall be grounded.

Grounding Sequence: When grounding lines or equipment, the grounding device shall first be attached to a known good ground connection and then to the circuit or equipment. In removing the grounds, first remove the connection to the circuit or equipment and then remove the ground connection. **Under no circumstances are grounding cables to be daisy-chained in lieu of using the proper length of cable.**

Grounding Tools: An approved live-line tool shall be used to make or remove the grounding connection to the circuit or equipment.

Personal Protective Equipment (PPE): All PPE required for testing voltages, and placing/removing grounding devices, shall meet the requirements of the *Selection, Inspection, and Testing of Personal Protection and Testing Equipment* section of this manual.

Capacitors: Static capacitors must be grounded (discharged) before work is performed on them, even if there is no possibility for them to become energized. If the operating voltage of the capacitor is greater than 50 volts, then a five-minute waiting period is required between de-energizing the capacitor and applying the ground connection.

8.0 LIVE (ENERGIZED) WORK

8.1 Background

This policy describes the methods used by Ames Laboratory to promote safe work practices relating to work on energized circuits in accordance with *DOE Handbook, Electrical Safety, No. and 29 CFR 1910.331-335.* The policy is applicable to all such work performed by employees of Ames Laboratory.

8.2 Live (Energized) Work Policy

Within Ames Laboratory all work on energized systems having potentials in excess of 50 volts shall be performed only when necessary and then performed only by a QEW. Specifically, work on energized circuits shall be permitted only if there is no safe alternative and such activities comply with all applicable requirements of this chapter. Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits, which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards. If energized (live) electrical work is necessary, the Ames Laboratory Safe Work Permit for Energized Electrical Work must be completed.

8.2.1 Personal Protective Equipment (PPE) Required

When activities involving exposure to live (energized) voltages greater than 50 volts are performed and such acts will place the QEWs in proximity to exposed, energized electrical parts, appropriate PPE shall be utilized. Such PPE may include the following items but see the specific requirements list in *Appendix E Work Matrices* (refer to Section 12.2):

- Safety glasses or face shields
- Rubber insulated gloves
- Rubber insulating blankets
- Flame Resistant clothing

The selection of appropriate PPE shall be approved by the QEW's supervisor.

8.2.2 Examples When Live (Energized) Work May Be Required and Allowed

- System calibration procedures where proper adjustments can only be made with the system energized. Appropriate approvals must be obtained.
- Repair and maintenance procedures where power application is necessary to perform tests and/or adjustments. Appropriate approvals must be obtained.

- Adding or replacing a circuit breaker by FES personnel when shutting off all power would create additional hazards. Appropriate approvals must be obtained (Safe Work Permit for Energized Electrical Work).

Justification of Need:
Live parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Energized parts that operate at less than 50 volts to ground shall not be not required to be de-energized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

FPN No. 1: Examples of increased or additional hazards include, but are not limited to, interruption of life support equipment, deactivation of emergency alarm systems, and shutdown of hazardous location ventilation equipment.

FPN No. 2: Examples of work that might be performed on or near exposed energized electrical conductors or circuit parts because of infeasibility due to equipment design or operational limitations include performing diagnostics and testing (e.g., start-up or troubleshooting) of electric circuits that can only be performed with the circuit energized and work on circuits that form an integral part of a continuous process that would otherwise need to be completely shut down in order to permit work on one circuit or piece of equipment.

FPN No. 3: For voltages of less than 50 volts, the decision to de-energize should include consideration of the capacity of the source and any overcurrent protection between the energy source and the worker.

8.2.3 Live (Energized) Work

The following safety work practices are required when working in proximity to exposed and energized parts (e.g., electrical motor control centers, distribution center panels and associated lines, laboratory power control systems, open chassis under repair and/or calibration, etc.)

8.2.3.1 Qualified Safety Watch Person

If a safety watch person is required for energized work (*Appendix E Work Matrices*) he/she shall be a QEW and should have a current CPR certification.

8.2.3.2 Shutdown versus Isolation and Insulation

Before beginning any construction or maintenance work that requires activities other than those covered in item 8.2.3.4 below and that will place the worker(s) in proximity to exposed energized electrical parts, the system or device being worked upon shall be totally de-energized or the area of the work shall be isolated and insulated. The decision to isolate and insulate rather than to de-energize must be made by a QEW(s) involved. Live parts that operate at less than 50 volts to ground need not be de-energized if there will be no increased exposure to electrical burns or explosion due to electric arcs.

8.2.3.3 Electrical Hazards Review

As a part of the job instruction related to those tasks covered in item 8.2.3.2, a Qualified Person will review and discuss the specific hazards involved with the worker(s) who will perform the task(s). A decision to isolate/insulate rather than to de-energize will be discussed, and if affirmed, the methods of isolation/insulation to be used shall be detailed. For facilities equipment a flash hazard analysis may be required.

Safe Work Permit and Energized Work Standard Operating Procedures:
The review and discussion of all hazards and work plans must be documented.

For energized work the Ames Laboratory Safe Work Permit for Energized Electrical Work form shall be utilized before commencing any work. Approval of the Group Leader/Department Manager, Electrical Safety Committee (designee), and Chief Research Officer (CRO)/Chief Operations Officer (COO) are required.

8.2.3.4 Live (Energized) Work Precautions

Electrical or electronic servicing (maintenance) activities that utilize electrical motor control centers, distribution centers, lines or field devices, R & D equipment, and/or similar devices to be energized, require special precautions by the QEW performing these activities.

Activities covered by this practice may include:

- Preventive maintenance observations and meter checks;
- System tuning;
- Trouble-shooting;
- Routine fuse replacement; and
- Resetting device overloads.

8.2.3.5 Tool Selection for Live (Energized) Work

All tools used in conjunction with approved live (energized) work activities shall be insulated and of an approved design for the voltages expected to be encountered.

8.2.3.6 Approach Boundaries to Live Parts for Shock Protection

(All dimensions are distance from live part to employee.)

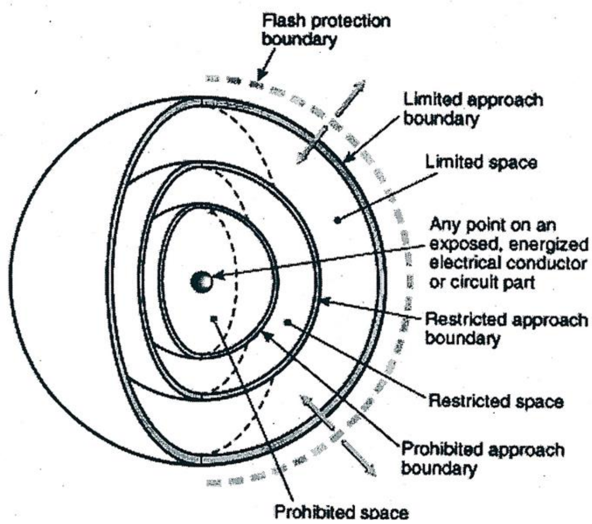
Limited Approach Boundary*

1	2	3	4
Nominal System Voltage Range, Phase to Phase	Exposed Movable Conductor	Exposed Fixed Circuit Part	Restricted Approach Boundary1; Includes Inadvertent Movement Adder
Less than 50	Not specified	Not specified	Not specified
50 to 150	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	Avoid contact
151 to 750	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	0.30 m (1 ft 0 in.)
751 to 15 kV	3.05 m (10 ft 0 in.)	1.53 m (5 ft 0 in.)	0.70 m (2 ft 2 in.)

15.1 kV to 36 kV	3.05 m (10 ft 0 in.)	1.83 m (6 ft 0 in.)	0.80 m (2 ft 7 in.)
36.1 kV to 46 kV	3.05 m (10 ft 0 in.)	2.50 m (8 ft 0 in.)	838.2 mm (2 ft 9 in.)
46.1 kV to 72.5 kV	3.05 m (10 ft 0 in.)	2.50 m (8 ft 0 in.)	1.00 m (3 ft 2 in.)
72.6 kV to 121 kV	3.30 m (10 ft 8 in.)	2.50 m (8 ft 0 in.)	1.00 m (3 ft 3 in.)
138 kV to 145 kV	3.40 m (11 ft 0 in.)	3.05 m (10 ft 0 in.)	1.20 m (3 ft 7 in.)
161 kV to 169 kV	3.60 m (11 ft 8 in.)	3.60 m (11 ft 8 in.)	1.30 m (4 ft 0 in.)
230 kV to 242 kV	4.00 m (13 ft 0 in.)	4.00 m (13 ft 0 in.)	1.70 m (5 ft 3 in.)
345 kV to 362 kV	4.70 m (15 ft 4 in.)	4.70 m (15 ft 4 in.)	2.80 m (8 ft 6 in.)
500 kV to 550 kV	5.8 m (19 ft 0 in.)	5.8 m (19 ft 0 in.)	3.60 m (11 ft 3 in.)
765 kV to 800 kV	7.24 m (23 ft 9 in.)	7.24 m (23 ft 9 in.)	4.90 m (14 ft 11 in.)

Note: For Flash Protection Boundary, see 2015 NFPA70E, 130.5(A).
Table summarized from NFPA 70E 2015..
*See definition in Article 100 and text in 130.4(D)(2) and Annex C for elaboration.

8.2.3.7 Limits of Approach



8.2.3.8 Limits of Approach

LIMITS OF APPROACH

Prohibited Space	Prohibited Approach Boundary	Restricted Space	Restricted Approach Boundary	Limited Space	Limited Approach Boundary		Flash Protection Boundary
Consider the same as touching an energized conductor or circuit part.		• No unqualified employee allowed. • Documented plan authorized by management. • Use PPE appropriate for working near exposed conductors or circuit parts. • Minimize risk of inadvertent movement.		• Unqualified employee allowed if continuously escorted by qualified employee.		• Unqualified employee allowed. • Must wear PPE • Under close supervision of QE.	

Figure 8.2 Limits of Approach

Distances vary with system voltage. See 8.2.3.6 for boundary distances.

9.0 DESIGNING FOR ELECTRICAL SAFETY

9.1 Background

Designers of electrical systems and equipment are confronted by many issues of codes and standards with which they must be concerned. This chapter is not intended to represent a complete design standard, but to impose minimum criteria necessary to incorporate electrical safety concerns as part of the design of any electrical systems or equipment. This policy applies to all electrical design work performed by employees of Ames Laboratory.

9.2 Designing for Electrical Safety

Ames Laboratory shall ensure that electrical safety considerations are included as part of the design rationale for electrical systems or equipment.

9.2.1 General Requirements

In order to provide maximum protection from electrical hazards to the public, Ames Laboratory employees and contractors, all electrical systems and/or equipment shall be designed in accordance with all federal, state, and local codes, and consensus standards.

9.2.2 Use Justification

Consideration shall be given to the application of electrical conductors, components, equipment and systems as it relates to the anticipated work environment. Considerations may include the following:

- Use of approved electrical conductors, components, equipment and systems for the intended application;

- Mechanical strength and durability for all anticipated applications;
- Electrical considerations such as insulation, heat arcing effects and rating for all anticipated applications;
- Locations of grounding connections to maximize personal protection and accessibility;
- Location and/or minimization of potential electrical hazard contact points for user or maintenance activities; and
- Lockout/tagout capabilities.

Electrical conductors, components, equipment and systems shall be used as indicated by manufacturer recommendations, listings and labels, or as preapproved by the AHJ.

9.2.3 Equipment Identification Requirements

Equipment shall have labels or similar sources of information placed in easily accessible locations. Labels shall identify descriptive and/or functional use, voltage, current, wattage, and other appropriate information.

All equipment and features (e.g., switches and controls) subject to operation or manipulation shall be properly identified as to its operational/equipment use by signage of appropriate size and location to be easily read by operating personnel.

Appropriate caution and warning signs shall be applied in conspicuous locations.

All labels, signs or other markings shall be environmentally durable.

All hardwired electrical equipment shall have the source of power (panel board and breaker number) identified by a label, sign or other marking. All circuit breaker panels, disconnects, and control centers shall be marked with appropriate arc/flash warning labels.

Illumination levels shall be provided so that at no time will the level of illumination become a factor contributing to a potential electrical accident, either from too little or too much illumination.

9.2.4 Requirements for Systems of 600 Volts or Less

The following considerations shall be included in the design of systems and equipment using voltages of 600 volts or less.

9.2.4.1 Workspace Dimensional Clearance about Electrical Equipment

It is important that sufficient working space and access be provided and maintained about all electrical equipment to permit workers to safely operate and/or perform maintenance on the equipment. Considerations shall be given to anticipate the physical changes in the workplace and the variety of materials which may be taken into the vicinity of the electrical equipment. Minimum workspace clearance requirements for systems of 600 volts and less are shown in Figure 9.1 below.

Floor Marking Below Permanent Electrical Disconnect Equipment: Access to permanently mounted electrical circuit breaker panels or disconnecting means shall remain clear of obstructions. In order to delineate the required access clearances, the floor may be marked with yellow tape. This marked area may not be used for temporary/permanent storage or equipment.

New Installations: FES personnel will mark the floor when they install the disconnecting device for new installations.

Existing Equipment: ESH&A or an AHJ designated person shall mark the floor when problem areas are encountered during inspections.

Exempted Equipment: Disconnecting means that are properly locked out or unused (not connected to equipment) and marked shall be exempt until the lock is removed or the equipment is reconnected. Circuit breaker panels in hallways do not require floor markings.

9.2.4.2 Guarding of Energized Parts

Primary consideration shall be given to insulating, isolating, or otherwise effectively guarding energized electrical equipment parts to afford the electrical worker the highest level of safety. Energized electrical parts may be positioned overhead to prevent inadvertent contact in controlled areas. When entering these areas, workers shall use extreme caution when carrying long conductive objects. Exposed energized parts shall never be less than 8 feet above the floor or other working surface.

Entrances to locations where there are exposed energized electrical parts shall be marked with danger signs indicating the electrical contact hazard and the voltage level. The signs shall also indicate entry by QEWs only.

9.2.4.3 Wiring Systems and Enclosure Design

- Grounding (green) conductors shall be distinguishable from all other conductors.
- Bonding conductors may employ braided straps or other appropriate, uninsulated material.
- A grounded conductor shall not be used to reverse designated polarity.
- Equipment grounding conductors shall be run with all current-carrying conductors.

9.2.4.4 Branch Circuits

- Branch circuits shall conform to the National Electrical Code.
- All device ratings shall be consistent with the branch circuit capacity.

9.2.4.5 Overcurrent Protection

- Conductors and equipment shall be protected from overcurrent in accordance with their ability to safely conduct current.
- Circuit breakers shall clearly indicate their open (off) or closed (on) position.

9.2.4.6 Wiring Methods

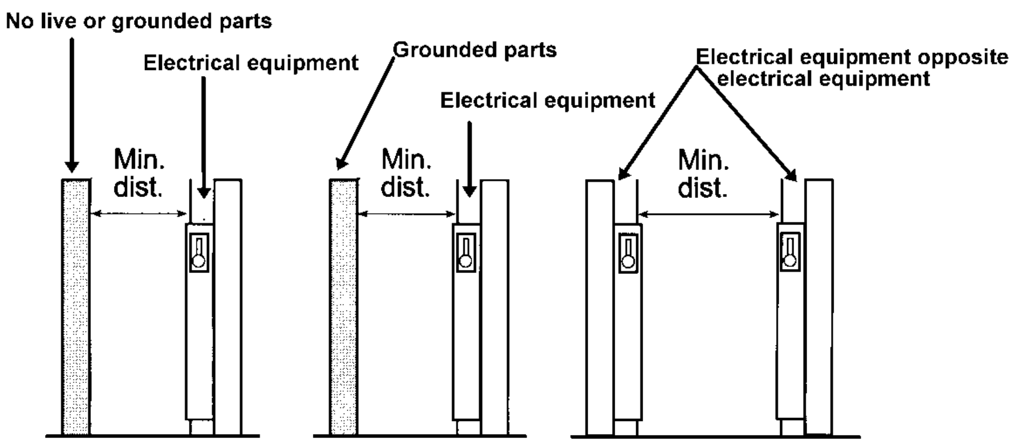
Metal enclosures, raceways, conduits, etc., for conductors shall be continuously connected to assure electrical continuity. Wiring and equipment shall not be installed in locations classified as hazardous according to *NEC, Article 500* unless approved by the ESC, and the wiring and equipment are approved by the manufacturer for such installations and installed appropriately. Unused openings in cabinets, boxes and fittings shall be appropriately and effectively closed.

9.2.5 Requirements for Systems Greater Than 600 Volts

In addition to applicable requirements listed in Section 9.2.4 above, conductors and equipment used on circuits greater than 600 volts shall comply with the following requirements.

Exposed Conductors: No conductors of voltages greater than 600 volts shall be exposed.

Work Space Dimensional Clearance about Electrical Equipment: Minimum workspace clearance requirements for systems greater than 600 volts are shown in Figure 9.1.



Condition 1		Condition 2		Condition 3	
Volts to ground	Min. dist.	Volts to ground	Min. dist.	Volts to ground	Min. dist.
0 - 150 V	3 ft.	0 - 150 V	3 ft.	0 - 150 V	3 ft.
150 - 600 V	3 ft.	150 - 600 V	3 1/2 ft.	150 - 600 V	4 ft.
601 - 2,500 V	3 ft.	601 - 2,500 V	4 ft.	601 - 2,500 V	5 ft.
2,501 - 9,000 V	4 ft.	2,501 - 9,000 V	5 ft.	2,501 - 9,000 V	6 ft.
9,001 - 25,000 V	5 ft.	9,001 - 25,000 V	6 ft.	9,001 - 25,000 V	9 ft.
25,001 V - 75 kV	6 ft.	25,001 V - 75 kV	8 ft.	25,001 V - 75 kV	10 ft.
Greater than 75 kV	8 ft.	Greater than 75 kV	10 ft.	Greater than 75 kV	12 ft.

Figure 9.1 Summarized from NEC Table 110-16 (a) and NEC Table 110-34 (a)

Enclosures for Electrical Installations: Areas open to unqualified persons shall have metal enclosed equipment. Access to these areas shall be controlled by a lock (restricted by controlled issuance of keys) if equipment enclosing is not feasible.

9.2.6 Engineered Safety Systems

Engineered Safety Systems, (Appendix B) shall be designed and constructed in accordance with the following mandatory requirements.

9.2.6.1 Designation by Ames Laboratory

The Ames Laboratory SRC and ESC shall be responsible for designating systems as Engineered Safety Systems.

9.2.6.2 Engineered Safety Systems Review Required

ESH&A (or their designee) shall perform any required review of Engineered Safety Systems.

9.2.6.3 System Design Description Required

For Engineered Safety Systems, the Electronics Shop shall prepare written System Design Descriptions (SDDs) answering any and all points contained in the review of an Engineered Safety System. The SDD shall be of sufficient detail that members of the SRC and ESC can clearly understand the extent to which all points of concern are addressed. In addition, the SDD shall address other system considerations, including (but not limited to) system reliability considerations, failure modes and consequences, fail safe features, confidence testing prior to operation, maintenance procedures and periods, and operational procedures.

9.2.6.4 Design Review Required

Any SDD for engineered safety systems shall be approved for fabrication by the SRC and ESC in response to a formal design review meeting for developmental approval.

9.2.6.5 Required Signage

All principle modules and conduits of engineered safety systems shall be clearly and distinctively labeled.

9.2.6.6 Preoperational Inspections

All engineered safety systems shall be inspected prior to operation by an electrical inspector approved by the ESC. Specific inspection concerns shall include (but are not limited to) adequacy of documentation, system performance during confidence testing, system reliability considerations, documented testing of failsafe features, existence of maintenance procedures and schedules, existence of operational procedures, and adherence to accepted codes and standards.

9.2.6.7 Repair and Maintenance of Engineered Safety Systems

Repair and maintenance of engineered safety systems shall be performed only by the original manufacturer (or their approved designee) or by Electronics Shop.

9.2.7 Underground Systems/Floor and Wall Conductors

All new underground services shall be designed and constructed in accordance with all applicable federal, state, local, and national consensus standards, and in such a manner as to afford maximum protection for the safety of the public as well as all Ames Laboratory employees.

All underground systems shall be identified on an up-to-date drawing which shall be maintained by FES and readily available for reference.

Locating equipment shall be used in addition to as-built drawings to insure safety before cutting or drilling takes place. Proper procedures shall be used with the appropriate locating equipment (Appendix G.).

10.0 ACQUISITION, FABRICATION AND MAINTENANCE OF ELECTRICAL EQUIPMENT

10.1 Background

To protect Ames Laboratory personnel from hazards arising from inadequate control of the equipment procurement, design, fabrication, assembly, and ongoing maintenance processes, some form of control is necessary to ensure the equipment's electrical integrity. This policy describes the mechanisms used by Ames Laboratory to accomplish these objectives.

This policy affects all Ames Laboratory personnel involved in the selection, specification, requisition, fabrication, and installation of electrical equipment.

10.1.1 Applicable Orders and Codes

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance, suggests maintenance procedures for certain electrical equipment while recommending general electrical preventive maintenance as appropriate. The Acquisition, Fabrication, and Maintenance of Electrical Equipment section describes the mechanisms used by Ames Laboratory to implement these Orders and codes. Additionally Ames Laboratory must comply with the provisions of the *DOE Electrical Safety Handbook,* regarding NRTL certification or prior approval by the AHJ, electrical equipment inspection and Section 10.2.8 below titled *General Electrical Preventive Maintenance*.

10.2 Acquisition, Fabrication, and Maintenance of Electrical Equipment

Ames Laboratory shall promote electrical safety by requiring the use of equipment known to have been designed with electrical safety concerns in mind. The programs/groups/sections shall develop inspection and periodic maintenance procedures to assure that electrical equipment remains in a safe condition during its operating lifetime.

The following steps are required to place any electrical equipment into service and to ensure its continued operation throughout its functional lifetime:

- Specification and purchase or design and fabrication;
- Acceptance and installation;
- Operation of equipment for some functional lifetime; and
- Periodic inspections and appropriate maintenance during its functional lifetime.

10.2.1 Specification of NRTL-Certified Equipment

Electrical equipment and systems shall be NRTL-Certified unless equipment or systems possessing NRTL certification are not available for purchase. Any equipment or systems that have not been NRTL-Certified must be inspected by an electrical inspector approved by the AHJ prior to operation.

Exempted Items: Electrical equipment possessing less than 50 volts and incapable of sustaining a high current arc of a damaging nature does not require NRTL certification unless used in a hazardous environment or for electrical measurements.

Manufacturer-Approved Replacement Parts or Upgrades Exempted: Manufacturer-approved replacement parts and manufacturer-approved equipment upgrades for NRTL-certified equipment do not require NRTL certification.

10.2.2 Design and Fabrication of Electrical Equipment
Design and fabrication of electrical equipment shall be performed by a QEW.

10.2.3 Inspection of Purchased Electrical Equipment Prior to Initial Operation
New electrical equipment subject to preventive maintenance procedures will be inspected prior to initial operation by an electrical safety inspector approved by the AHJ. The initial inspection record will become a part of the preventive maintenance record.

10.2.4 Inspection of Fabricated Electrical Equipment
All locally fabricated electrical equipment will be subject to inspection for compliance with applicable electrical safety codes and standards by an electrical safety inspector approved by the AHJ. A record of the inspection (Approval Criterion of Unlisted Electrical Equipment form) will be filed by the group/section responsible for operation of the equipment and, where appropriate, a copy of the inspection will become a part of the preventive maintenance record.

10.2.5 Inspection of Rebuilt/Modified Electrical Equipment
Prior to returning the equipment to operation, all rebuilt or modified electrical equipment will be subject to inspection by an electrical safety inspector approved by the AHJ. If the rebuild/modification is done by the original manufacturer or by an outside party with preapproval by the AHJ, then inspection will be done in accordance with Section 10.2.4; otherwise inspection will be done in accordance with Section 10.2.5.

10.2.6 Ground Fault Protection
The FES has installed Ground Fault Circuit Interrupters (GFCIs) throughout the Ames Laboratory as a function of utility distribution. FES shall install additional GFCIs as conditions warrant. Provision for the maintenance of GFCIs by a QEW shall be the responsibility of the group/section in which these devices reside. GFCIs shall be inspected and ground current trip tested at intervals recommended by their manufacturer.

10.2.7 General Electrical Preventive Maintenance
Items covered in this section include maintenance requirements for electrical installations and equipment that relate directly to employee safety in the workplace and are not specifically covered elsewhere in this manual. It is not the intent of this section to define specific maintenance methods since there may be several approaches that will satisfy the act of testing, preserving or restoring affected equipment to a safe working condition.

- All grounding and bonding shall be maintained and tested.

- All safety interlocks shall be maintained in proper working condition with documentation showing location, dates tested, and intervals of testing.
- Equipment identification and safety-related operational instructions shall be securely attached and in legible condition.
- All protective covers, doors and enclosures shall be properly in place.

- All portable tools, lamps, extension cords and other equipment (see the Tools and Test Equipment section) shall be tested, inspected and maintained so that:
    - There are no breaks, damage or cracks that expose live parts;
    - Electrical cord terminations have no stray strands or loose terminals;
    - There are no loose or missing cover plates;
    - Electrical polarity is correct; and
    - Extension cords have continuous ground.

Physical protection systems shall be a part of the preventive maintenance program. These systems include, but are not limited to fences, cubicles and enclosures that guard against unauthorized access or accidental contact with live parts.

Updated drawings and instructions for operation, maintenance and testing of modified systems shall be made available to service personnel responsible for preventive maintenance.

11.0 TOOLS AND TEST EQUIPMENT

11.1 Background

Electrical tools and test equipment can enhance the operation of equipment and aid the progress of R&D activities. Proper use of these tools and test equipment will ensure the safety of personnel and the safe use of equipment under maintenance or modification.

11.2 Electrical Tools and Test Equipment Policy

Electrical tools, test instruments, and equipment shall be used by QEWs in accordance with *29 CFR 1910.334(c)*. In addition, a QEW will inspect all test instruments and equipment to ensure the equipment is safe to use. Any tools or equipment identified as unsafe shall be tagged out of service and not used until the hazards have been mitigated (see Section 11.2.2.4).

11.2.1 Hand Tools

Hand tools are portable and designed for unassisted use by a worker. The following guidelines apply to hand tools.

- All tools used for electrical work shall be maintained in good working order.
- Only tools specifically designed for the task at hand shall be used. Use of "cheaters" and other hand or arm extensors is prohibited.
- Only insulated tools and equipment shall be used when the tools and equipment could contact energized or potentially energized conductors and exposed electrical parts.

11.2.2 Electrical Portable Power Tools

Electrical portable tools shall be used as intended by the manufacturer.

Guards: The source of energy for an electrical power tool shall be disconnected before tool accessories or guards are changed or adjusted. When electrically powered tools are designed to accommodate guards, or the guards are removed for adjustment, they shall be replaced in their correct position before use.

Eye Protection: Approved eye protection (e.g., goggles, face shields) shall be worn when using electrical portable power tools (see Section 12.2).

Storage: Portable power tools shall be properly stored when they are not in use. A power tool shall never be suspended by its power cord.

Inspection: Before each day's use, electrical power tools shall be visually inspected for external defects, such as deformed or missing pins, insulation damage, or indications of possible internal damage. Tools found damaged or defective shall be tagged out of service, and shall not be used until repaired.

Grounding: Electrical portable power tools (except double insulated or battery operated) shall be grounded by a grounding conductor which is contained within the same cord as the circuit conductors.

Electrical Portable Power Tools Grounding Conductors: All electrical portable power tools, which are required to be grounded, shall have their grounding conductors tested for continuity by a QEW. These tests shall be performed:

- Before initial use after purchase;
- Before a tool is returned to service following repair;
- Before a tool is returned to service after any incident which reasonably can be suspected to have caused damage; or
- At intervals not to exceed 12 months.

The test results shall be documented in logs in accordance with *NFPA 70B*. It is useful to color tag the tool to indicate its valid testing period.

Maintenance: Electrical portable power tools shall be cleaned and maintained in accordance with the manufacturer's instructions.

Annual Portable Power Tool Testing and Inspection: All portable or hand held electrical tools that have exposed conductive parts and operate on 120VAC or greater shall be tested annually. Battery powered tools or tools with no exposed conductive parts do not need to be tested. Conductive fasteners inserted in nonconductive housings are not considered exposed conductive parts. Typical examples of tools requiring annual testing:

- Power drills
- Power saws
- Power grinders
- Sanders and buffers
- Vacuum cleaners
- Floor scrubbers and polishers

Each program is responsible for annual testing of their applicable tools. Testing and inspection will be performed by FES QEWs or approved inspector with approved test equipment. Contact FES to request and coordinate annual testing. Equipment that passes all applicable tests will be labeled with the date and inspector's initials. Any equipment that fails testing or inspection shall be labeled by the inspector indicating the equipment shall not be used until repaired.

Ground Fault Circuit Interrupters (GFCIs): When used outside in wet or damp locations, electrical portable power tools shall be connected to Ground Fault Circuit Interrupters (GFCIs).

11.2.3 Extension Cords, Temporary Power Taps (TPTs), and Surge Protectors

Extension cords and temporary power taps (TPTs) providing temporary electrical power in the workplace shall be selected to provide protection for personnel and equipment and shall be used in a safe manner. Approved Power Taps and Power Centers may be used to provide permanent protection of computers, ADP equipment, and analytical instruments. Device descriptions and minimum requirements are listed in Appendix F. Approved devices are available at the Ames Laboratory storeroom. Power cords must be sized for the load and constructed of appropriate materials in accordance with the information provided in the *Requirements for Specific R&D Equipment* section of this manual and Table 14-1, *Allowable Ampacity for Flexible Cords and Cables*. Extension cords and TPTs shall not be used in place of the permanent wiring of the structure.

Selection: Extension cords and TPTs shall be:

- NRTL listed;
- Provided with built-in over-current protection (if a TPT);
- Suitable for the projected current load;
- Suitable for the particular environment involved; and
- Defect-free (no loose parts, no deformed or missing pins, no damaged outer jacket or insulation).

Use: Extension cords and TPTs shall be used properly and in a safe manner.

- Protect from damage at all times.
- A single extension cord may be used to supply power to a TPT.
- Remove the temporary power immediately upon completion of the test, experiment, or developmental work.

Prohibited Uses of Extension Cords and TPTs: Prohibited uses are:

- As a replacement for permanent structure wiring;
- Alteration of plugs or receptacles;
- Splicing of flexible cords;
- Coupling of extension cords, (i.e., daisy chaining is not allowed);
- Coupling of TPTs (i.e. daisy chaining is not allowed);
- Using a flexible cord to raise or lower equipment;
- Fastening a flexible cord with any device that could damage the outer jacket or insulation;
- Concealing flexible cord within walls, floors or ceilings;
- Covering a flexible cord with carpets, or other floor coverings;
- Running a flexible cord through holes in walls, floors, or ceilings (except as allowed under Section 11.2.3.2.2);
- Using adapters that interrupt the continuity of the grounding; and

- Using wet hands to plug a flexible cord to be energized, or to unplug a flexible cord to be de-energized.

Routing of Extension Cords: Extensions cords may be run through doors, windows, or floors only when all of the following conditions are met:

- No other outlet is available;
- Cords are protected from damage;
- Cords are taped down as required to mitigate tripping hazards; and
- Cords shall be disconnected after use and at the end of each day.

11.2.4 Test Equipment

Test equipment shall be operated and maintained according to the manufacturer's specification.

- Only listed and accepted equipment shall be used.
- Test equipment shall be adequately rated for the test being performed.
- All required PPE shall be worn while operating the test equipment.
- Test equipment shall be checked for proper operation immediately before each test, and immediately after each test.

11.2.5 Portable Ladders

Portable ladders shall have non-conductive side rails if they are used where the person or the ladder could contact exposed energized parts.

11.2.6 Personal Protective Equipment (PPE)

Personal Protective Equipment (PPE) shall be used by all people who are exposed to the risk of electrical shock, such as when in proximity to energized or potentially energized conductors or to exposed electrical parts see Section 12.2 and Appendix E, for specific requirements. Conductive articles (rings, metal watchbands, metal-framed eye wear, dangling jewelry, etc.) shall not be worn in proximity to energized or potentially energized parts.

12.0 SELECTION, INSPECTION AND TESTING OF PERSONAL PROECTION AND TESTING EQUIPMENT

12.1 Background

Live-line tools, personal protection equipment and electrical test equipment shall be maintained in a safe, reliable condition and shall be periodically inspected and/or tested as specified in the following guidelines.

12.2 Selection, Inspection, and Testing of Personal Protection and Testing Equipment Policy

QEWs shall select, inspect, and test all personal protection and testing equipment to ensure the best possible protection from exposed energized parts is provided.

12.2.1 Rubber Personal Protective Equipment

Selection of rubber insulating equipment shall meet the following national consensus standards.

- **Rubber Insulating Gloves:** *ASTM D 120-87* (or current edition), specification for rubber insulating gloves.

- **Rubber Insulating Sleeves:** *ASTM D 1051-87* (or current edition), specification for rubber insulating sleeves.
- **Rubber Insulating Blankets:** *ASTM D1048-88* (or current edition), specification for rubber insulating blankets.
- **Rubber Insulating Covers:** *ASTM D 1049-83* (or current edition), specification for rubber insulating covers.
- **Rubber Insulating Matting:** *ASTM D 178-88* (or current edition), specification for rubber insulating matting.

Refer to Table 12-1 for rubber insulating equipment in-service use voltage requirements.

Table 12-1

RUBBER INSULATING EQUIPMENT IN-SERVICE USE VOLTAGE REQUIREMENTS		
Class Designation	Maximum Use AC Voltage (Volts)	Label Marking Where Applicable
0	1,000	Red
1	7,500	White
2	17,000	Yellow
3	26,500	Green
4	36,000	Orange

Note: This Table is based on American Society for Testing and Materials (ASTM) Standards

12.2.1.1 Inspection

The following specific requirements apply to the inspection of rubber insulating glove sleeves, blankets, line hose and covers.

Glove Inspection and Storage: Gloves shall be given an air test before each day's use and immediately following any incident that can reasonably be suspected of having caused damage. The air test will assist in identifying, but will not always identify, points of damage causing leakage.

- The air test is performed by "rolling" the opening of the glove toward the fingers to create a seal and prevent trapped air from escaping. Do not blow air into glove. If leakage is detected, the glove shall be properly disposed of. Refer to ASTM D 120-87.
- Gloves should be removed from leather protectors and stored flat, right side out in a protective case or canvas bag.

Rubber Insulating Equipment Testing: Rubber insulating equipment shall be inspected for damage before each day's use and immediately following any incident that can reasonably be suspected of having caused damage.

Defective Rubber Insulating Equipment: Insulating equipment with defects that might affect its insulating properties shall immediately be removed from service and returned for dielectric testing as required. Examples of defects include:

- A hole, tears, puncture, or cut;
- Ozone cutting or ozone checking;
- An embedded foreign object;
- Any of the following texture changes: swelling, softening, hardening, or becoming sticky or inelastic; and
- Any other defect that damages the insulating properties.

12.2.1.2 Testing

Rubber insulating protective equipment shall be subjected to periodic dielectric tests.

Electrical Testing of Rubber Insulating Gloves and Sleeves: Electrical testing of insulating rubber gloves and sleeves shall be in accordance with ASTM Designation: F496-85 (or current edition) titled, *Standard Specification for the In-Service Care of Insulating Gloves and Sleeves*. Rubber insulating gloves and sleeves shall:

- Be dielectrically tested before first use and every six months thereafter.
- Be dielectrically retested if damage is suspected.
- Have diaelectrical tests documented, and the gloves so identified with a stamped test date on the upper cuff. Stamp ink shall not damage the glove material, adversely affect the glove's insulating value or cause other electrical safety concerns.

Electrical Testing of Rubber Insulating Blankets: Electrical testing of rubber insulating blankets shall be in accordance with *ASTM Designation: F479-83* (or current edition) titled, *Standard Specification for In-Service Care of Insulating Blankets.* Rubber insulating blankets shall at a minimum:

- Be dielectrically tested before first use and every 12 months thereafter.
- Be dielectrically retested if damage is suspected.
- Have electrical tests documented and the blankets so identified with a stamped test date and identification number. Stamp ink shall not damage the blanket material, adversely affect the blanket's insulating value or cause other electrical safety concerns.

Testing of Rubber Insulating Matting: Currently there is not an ASTM standard for in-service use and testing of rubber insulating matting. Refer to the manufacturer's recommendations and the *ASTM Designation D 178-88* (or current edition) titled, *Standard Specification for Rubber Insulating Matting* for manufacturers' requirements in dielectrical testing.

12.2.2 General Requirements for Personal Protective Equipment (PPE)

Equipment shall be appropriate for the specific parts of the body to be protected and for the work to be performed.

12.2.2.1 Maintenance of Protective Equipment

Protective equipment shall be maintained in a safe reliable condition and shall be inspected periodically and/or tested as required. Equipment which is damaged, or fails to pass test requirements, shall be replaced.

12.2.2.2 Eye and Face Protection

Approved eye wear shall be worn at all times while working near energized or potentially energized conductors or to exposed uninsulated parts that may become energized. Such eyewear shall meet the requirements of *ANSI Z87.1*.

- Eyewear shall not have exposed metal parts, or they shall be covered by approved goggles or face shield when performing live (energized) work.
- When additional protection like a face shield is required during specific operations, approved eyewear shall be worn underneath the face shield.
- Tinted eyewear shall not be worn in reduced lighting conditions which may compromise worker safety.

12.2.2.3 Foot Protection

Foot protection meeting ANSI Z41 standards shall be worn as required.

Electrical Hazard Rated Footwear: Personnel wearing electrical hazard rated footwear should be equipped with grounding straps before entering "static-free" areas.

12.2.2.4 Head Protection

Non-conductive head protection shall be worn by workers when there is the potential to make contact with energized or potentially energized conductors and exposed live parts. Such head protection shall:

- Meet the requirements of *ANSI Z89.1*;
- Not be altered or defaced in any manner;
- Have hard hat liners, if used, constructed from approved material; and
- Not have markings containing conductive materials.

Recommendation: It is recommended that full-brimmed hard hats be utilized for increased neck and shoulder protection.

Inspection: All hard hat components should be visually inspected each day of use for signs of dents, cracks, penetration, and/or any damage that might reduce the degree of safety originally provided.

Maintenance: Hard hats should be maintained free from contaminates that may reduce insulating effectiveness, and should be cleaned following the procedures described in ANSI Z89.1.

12.2.2.5 Clothing

Fire resistant clothing (NOMEX® or equivalent) shall be worn if energized electrical hazards are present and not abated. Voltage, amperage, insulation, and isolation must be evaluated to determine if protective clothing is required.

12.2.3 Live-Line Tools

When selecting live-line insulating tools, refer to *ASTM Designation F 711-83* (or current edition) titled, *Standard Specification for Fiberglass - Reinforced Plastic (FRP) Rod and Tube Used in Live-Line Tools* and select tools that are:

- Of sufficient length to adequately protect the worker from inadvertent contact with exposed energized or potentially energized sources; and
- Rated for the highest expected voltage.

Inspection: At a minimum, live-line insulating tools:

- Shall be visually inspected for defects before each use. Examples of defects are cracks, splits and deformations.
- Shall be inspected for contamination before each use. Examples of contamination are surface moisture, oil and dirt.
- Shall utilize attachments which are inspected for damage that would limit the effectiveness or operation of the tool.
- Shall be tagged "out-of-service" and removed from service in the event that they become damaged.

Testing: Live-line tools shall be subjected to periodic dielectric tests in accordance with *ANSI/IEEE Standard 978-1984* (or current edition) titled, *IEEE Guide for In-Service Maintenance and Electrical Testing of Live-Line Tools*. Live-line tools shall as a minimum:

- Be dielectrically tested before initial use and every 12 months thereafter for fiberglass and epoxy rods.
- Be dielectrically tested before initial use and every 6 months thereafter for wooden rods.
- Be dielectrically retested if damage is suspected.
- Have electrical tests documented and tools so identified with an identifying test date and identification number. Identifying means shall not damage the tools or adversely affect the tool's insulating value.

12.2.4 Electrical Test Equipment

Electrical test equipment and its use shall meet the following minimum requirements:

- Be rated for the maximum voltage expected.
- Be checked for proper operation immediately before and immediately after the voltage test.
- Be maintained and operated according to manufacturer's specifications.
- All required personal protective equipment shall be worn while operating such test equipment.

12.2.5 Documentation

Records of all certifications and testing of personal protection and testing equipment should be maintained with document control provided by the program/department/group/section. The equipment user or the designated contact person is required to maintain an individual file folder for each equipment item.

13.0 RESEARCH AND DEVELOPMENT (R&D)

13.1 Background

This section applies to those people who are actively involved in R&D-oriented activities and to those who are visitors to the laboratories and work areas where such activities may be in progress. This chapter gives information, guidance, and suggested safe work practices which can reduce the potential of electrical shock and/or flash burn hazards to those R&D personnel, who, in the course of the experimentation process, may be exposed to energized or potentially energized electrical parts.

13.2 R&D Electrical Safety Policy

All R&D activities shall be performed in an electrically safe manner. The R&D environment presents electrical hazards which require knowledge and procedures beyond those detailed for general facilities use. The procedures included in this section address these specific issues. These procedures should be used in conjunction with applicable general practices covered in other sections of this manual.

13.2.1 Responsibilities of R&D Staff

Program Director/Department Manager, Group/Section Leader or Person-in-Charge (PIC): The program director/department manager, group/section leader or PIC is responsible for meeting all provisions of this chapter and other applicable chapter(s) of this manual.

Qualified Electrical Workers, Scientists, Post Doctorates, Graduate Assistants, Technicians and other Laboratory Researchers: QEWs, scientists, post doctorates, graduate assistants, technicians, and other Laboratory researchers shall comply with the portions of this section that apply to their own actions and conduct in the laboratory environment. They are also responsible for knowing and following the safe procedures and practices that are specific to their organization and laboratory.

Visitors: All visitors shall follow the safety regulations contained in this section and other safe procedures and practices as directed by the Laboratory activity supervisor or PIC.

Environment, Safety, Health, and Assurance (ESH&A): ESH&A shall be responsible for periodically auditing the effectiveness of the content and implementation of these guidelines. ESH&A shall also assist in recommending and supporting technical expertise in the implementation of these guidelines.

13.2.2 Safe Work Practices

Exposed Live Parts: All electrical equipment, testing devices, feeders, and power supplies shall be considered energized until tested or otherwise determined by a QEW to be de-energized and locked out and tagged out.

Rules and Guidelines: Rules and guidelines are directed to AC and DC systems except where noted.

Live Energized Work: It is the general policy of Ames Laboratory that service, maintenance or installation work performed on energized high voltage equipment or energized high voltage systems shall comply with all applicable requirements of the Live (Energized) Work section of this manual.

Conductive Articles: Conductive articles shall not be worn in proximity to energized or potentially energized parts. Articles not to be worn include such items as rings, metal watchbands, metal-framed eye wear, and dangling jewelry.

Use of PPE: PPE shall be used by all laboratory personnel who are exposed to the risk of electric shock, such as proximity to energized or potentially energized conductors, or exposed electrical parts (see Section 12.2).

Lockout/Tagout: All work on systems, circuits and equipment in the R&D laboratories shall be executed utilizing section five of the Ames Laboratory Environment, Safety, Health and Assurance Program Manual.

13.2.3 Grounding Practices

Before doing any work on de-energized high voltage equipment or lines, the equipment or lines shall be tested for voltage and properly grounded.

Visual Inspection: Before installing grounds, the grounding equipment shall be visually inspected to confirm equipment integrity.

Current Capacity: Safety ground sets shall be capable of conducting the maximum ground fault current which could flow at the point of grounding for the time necessary to clear the fault.

Equipment Grounding: All metal enclosures, equipment and structural components shall be grounded with recognizable, permanent grounding conductors. Equipment shall not be operated without proper grounding.

13.2.4 Safe Work Zone

Working space around electrical equipment shall be maintained as a safe work zone (refer to Section 6.2.7).

Temporary Installations: Because of the nature of the R&D process, some potentially hazardous pieces of equipment cannot be permanently installed and as such will require extra attention in providing appropriate facilities and methods to assure the safety of research personnel and visitors. These extra precautions may include:

- Physical barriers to prevent individuals from inadvertently contacting energized parts.
- Identifying hazardous areas and the nature of each hazard by such means as warning signs, flashing lights, audible alarms, or any combination thereof.
- Supplemental illumination shall be provided where necessary.

Permanent Installation: Refer to section 6.2.7 for information on safe zones, areas accessible to QEW, areas accessible to non-qualified persons, barricades, illumination, and/or confined/enclosed work spaces.

13.2.5 Hazardous Locations

Only QEWs shall install and service electrical equipment and systems in hazardous areas.

13.2.6 Portable Power Tools

Refer to section 11.2.2 for the proper use and care of all laboratory portable power tools.

13.2.7 Extension Cords, Temporary Power Taps, Flexible Cords

The use and care of extension cords, temporary power taps, and flexible cords are covered in section 11. Power cords must be sized for the load and constructed of appropriate materials in accordance with section 14.2.15.3 and Table 14-1.

13.2.8 Temporary Wiring

Recognizing the need for flexibility in the physical structure of experiments, and the probability of a short life requirement (30 days), wiring may be installed using temporary methods and techniques.

Temporary Installation: Temporary installations are those needed to support a specific test, experiment, or project and the temporary wiring is removed at its completion.

Wiring Techniques: Where feasible, experimental set-ups shall utilize permanent wiring techniques as outlined in pertinent codes, regulations, and/or Ames Laboratory approved practices.

Safeguards: When using temporary wiring techniques, extra efforts should be applied to maximize safeguards for personnel.

- Use multi-conductor rubber covered cord/cable wherever practical.
- Single conductors shall be bundled and secured, giving proper consideration to service use and voltage levels.
- All wiring shall be installed away from work activity areas, secured and appropriately marked with signs at points of possible personnel contact.

13.2.9 Cable Tray Applications in the R&D Laboratories

Cable Insulation/Separation: Laying power distribution cables and instrumentation cables in the same tray is not allowed unless the power cables are placed in a raceway (e.g., conduit).

Other Utilities: Cable trays may only contain cables and connectors. No utilities (such as steam, water, air, gas, or drainage) other than electrical are allowed in cable trays. Utilities required to support a project, test, or experiment may be attached to tray system supports provided that a minimum 1-5/8" clearance between the utility and the bottom of the tray is maintained.

Accessibility: Wire must be accessible in the tray.

Damage Prevention: Walking or climbing on cable trays is prohibited to prevent damage to the cables.

Cords: Extension cords and equipment cords may be run in a tray, but they shall be continuous and shall be rated for cable tray use. Outlets from extension cords must be suspended below the tray and be secured with a strain relief device to reduce strain on the cord and connectors.

Weight Limit: The weight limit of the tray or its support system shall not be exceeded.

Grounding: All conductive cable tray systems and raceways shall be grounded.

13.2.10 Ground Fault Circuit Interrupter (GFCI)

GFCI Near Sinks: GFCIs are required on all 120 volts, 15 and 20 amp receptacles within 6 feet of sinks (see Section 8.2.7).

GFCI Near Showers: Only GFCI protected electrical outlets and equipment rated at 120 volts, 15 and 20 amps shall be permitted from 3 to 6 feet from a shower head. Electrical outlets are not allowed within 3 feet from a shower head.

Non-GFCI Equipment: Electrical equipment which is neither GFCI-protected nor protected by suitable barriers shall be prohibited within 6 feet of the shower head. Building electrical distribution equipment (e.g., power panels) shall be at least 12 feet away from any shower head.

Safety Showers: Prior to installation, electrical equipment and outlets in the vicinity of a safety shower shall be approved by FES staff.

Testing: GFCIs should be tested using the test button on the front of the unit before each use or at least once a month.

13.2.11 Servicing Electrical Equipment and Systems

When feasible, all electrical service work should be performed with equipment and/or systems in a de-energized state as outlined in Section 13.2.3.

Energized Work and Personal Protective Equipment (PPE): When equipment and/or systems must be energized to facilitate the troubleshooting process, the worker shall insulate/isolate and/or wear appropriate protective equipment as directed in the following sections: Tools and Test Equipment; Selection, Inspection, and Testing of Personal Protection and Testing Equipment; and Live (Energized) Work.

Resetting Overload Devices: No overcurrent device, overload, or fuse shall be reset or replaced until the cause of the overload trip has been determined and corrected by a QEW. The repetitive, manual reclosing of circuit breakers, over-load devices and replacing fuses is prohibited.

Proper Use of Load Interrupters: No devices without load-interrupting capabilities shall be used as disconnecting means for energized circuits.

13.2.12 Safety Interlocks

Bypass Procedures: If interlocks or other protective systems must be bypassed or otherwise rendered inoperative to effect a proper maintenance test, then;

- Group/section leader, PIC, or activity supervisor approval must be obtained before safety interlocks are bypassed.

- The interlock devices/systems shall be returned to normal operation upon completion of testing.

13.2.13 Emergency Work vs. Experimentation

Personnel Safety: When emergency electrical repairs (power source device failure, for example) are required, personnel safety shall not be compromised to maintain continuity of the affected experiment(s).

Emergency Repairs and Live Work: If it is not feasible to interrupt an experiment in progress to make necessary emergency repairs, the provisions of section 6.2.5 shall be followed.

13.2.14 Modifications/Installations

De-energized Modifications: Modifications to facilities systems and experimental equipment to accommodate a revised or new experimental set-up shall be performed in a de-energized state.

Isolation/Insulation: When de-energization is not feasible, the Qualified Person involved must isolate/insulate him/herself from energized parts. (Refer to section 6.2.5.)

Documentation of Modifications: Any equipment which is originally listed by an Nationally Recognized Testing Laboratory (NRTL) (or equivalent) and that has subsequently been modified, thus voiding the NRTL certification, must be tracked within the group/section with documentation on file to verify the equipment is safe to operate as granted by the Ames Laboratory ESC (see Section 12.2.6).

13.2.15 Use of Nationally Recognized Testing Laboratory (NRTL) Listed Equipment

(See Section 13.2.2 Specification of NRTL-Certified Equipment)

Nationally Recognized Testing Laboratory (NRTL) Ratings: All electrical equipment including personal equipment such as radios and coffee pots, shall be listed, recognized, or certified by an NRTL, unless exempted by Section 10.2.2.1 or 10.2.2.2. Examples of an NRTL include Underwriters Laboratories (UL), Canadian Standards Association (CSA), or Factory Mutual Engineering Corporation (FMEC).

Local Approval: If the equipment is unique, manufactured in small volume, or if some other legitimate reason exists, it may be acceptable for the ESC to waive this requirement. If this requirement is waived, then the ESC must review and certify that all such equipment is safe to be operated within Ames Laboratory. However, the requirement is not to be waived if the same type of equipment sold by another manufacturer is labeled or listed. These requirements also apply to electrical equipment of foreign manufacture.

Custom Equipment: Purchased equipment manufactured to R&D specifications may be exempt from the NRTL approval requirements. However, such custom-made equipment or related installations, which are designed and fabricated for use by a particular customer, are acceptable if it is determined to be safe for its intended use by its manufacturer and by the ESC.

Equipment Built In-House: For equipment built in-house, the builder must provide documentation to assure the user the equipment is safe for its intended use. This documentation shall consist of a letter itemizing the inspections and tests which were performed to ensure safety. These may include items such as covers installed to prevent inadvertent contact with energized parts, grounding conductor continuity, proper voltages at terminals, wiring diagrams, schematics, and/or special procedures required.

Alternate Use of Equipment: Equipment or instruments which have been listed and/or labeled by an NRTL, such as UL, must be installed, used as intended, and used as instructed by the manufacturer per the listing. Any alternate use or modification of the equipment or instrument will void the listing and may present a dangerous electrical hazard to a user.

Cautions for Modifications: If electrical equipment or instrumentation must be modified, the person making the modification shall take all precautions to prevent the user or employee from the possibility of inadvertent, casual contact with any energized or stored electrical energy circuit greater than or equal to 50 volts AC (rms) or DC or stored energy capable of delivering an impulse of 10 joules or above. Any energized parts, which include items such as exposed terminals and connectors and buss bars, shall be covered and/or insulated to prevent inadvertent casual contact.

Documentation of Modified Equipment: Group/section leaders shall have documentation certified by ESC stating: all non-listed or non-labeled equipment is safe to operate and all listed or labeled equipment that has been modified, or is not being used for its intended purpose, is safe to operate.

13.2.16 Preventive Maintenance

Items covered in this section include maintenance requirements for electrical installations and equipment which relate directly to employee safety in the work place and are not specifically covered elsewhere in this manual. It is not the intent of this section to define specific maintenance methods since there may be several approaches that will satisfy the act of testing, preserving or restoring. See also Section 10.2.8, General Electrical Preventative Maintenance, herein before and NFPA 70B.

General Safety Requirements: All grounding and bonding systems shall be maintained and tested.

Clearances: Working spaces around and escape routes from electrical equipment shall be kept clear and unobstructed.

Safety Interlocks: Safety interlocks shall be maintained in proper working condition and proof-tested at regular intervals.

Posted Information: Equipment identification and posted safety related instructions shall be securely attached and maintained in legible condition.

Warnings: Warning signs shall be generously distributed, securely attached, and maintained in legible condition.

Closure: All protective covers, doors, and other enclosing systems shall be in place to insure that no unprotected openings exist.

Wiring Separation: Open wiring systems shall be separated from personnel work areas by a barrier or physical location.

Damaged Cables: Worn, frayed, or damaged flexible cables shall be removed from service and repaired or destroyed.

Maintenance: Attachment plugs, receptacles, cover plates, and connectors shall be maintained so that the following statements are true.

- There are no breaks, damage, or cracks exposing live parts.
- Terminations shall have no stray strands or loose terminals.
- There are no missing or bent blades, pins, or contacts.
- There are no missing cover plates or knockouts.
- Polarity is correct.

Tool Use in Damp Locations: All portable power tools, lamps, and extension cords shall be verified as safe and appropriate prior to use in damp, wet or conductive locations. Verifications shall confirm proper polarity, and that conductors are continuous and insulation is intact before initial use. These tools shall be inspected at 12 month intervals thereafter, and prior to service following repairs or modifications. When used outside or inside in wet or damp locations, electrical devices shall be connected to GFCIs.

Unexpected Wet Locations: Working in wet areas with electricity requires caution! Water can be a good conductor of electricity. The human body will become more conductive when clothing or shoes are wet. Avoid touching the electrical devices with wet hands or standing on wet floors.

When unexpected hazards are discovered such as water leaks, caution must be used with energized equipment. Immediately call FES (4-3756). After hours call Plant Protection (4-3483) to report the leak and get assistance with the cleanup. If possible without entering a hazardous area (standing water), shut off the water leak source and turn off the electrical power at the circuit breaker panel or switch. After the power has been removed and the water leak stopped, use fans to dry the room and equipment. Do not energize wet equipment or touch wet power plugs. Call the Electronics Shop (4-4823) if you need assistance.

13.2.17 R&D Laboratory Areas

Small Signal and ADP Equipment Wiring: The following wiring methods shall be used with permanent or temporary R&D equipment/wiring installations consisting of interior circuits for limited electrical power, control, signaling, data communication, and data acquisition. Small Signal and ADP Equipment Wiring systems (see Appendix B) which are contained in one laboratory space with all subsystems being contiguous shall be installed, operated, maintained, and/or repaired (at 50 volts or greater, or high current) by QEW staff from within the group/section. This is also the recommended practice when work is performed below 50 volts. The group/section may request QEW professional staff within the Technical and Administrative Services Division to perform the work.

Small Signal and ADP Equipment Wiring systems which are not in one laboratory space and require: i) structurally supported equipment and raceways; ii) penetration of walls and otherwise changing the building structure; iii) installation of signal cabling external to laboratory space including termination of signal devices; or iv) modifications of telecommunications shall only be performed by QEW professional staff within the Technical and Administrative Services Division. (See Section 3.6)

Laboratory Work Areas: Since many system set-ups are considered temporary experimental configurations, additional efforts shall be used to ensure that:

- Clearances are maintained for personnel work space and access to electrical equipment;
- Grounding and bonding system(s) integrity is maintained; and
- Special warning signs and barricades are in place.

Safety Watch: When working on electrically hazardous equipment, a second QEW shall be present to help in case of an emergency.

Testing of Protective Devices: Protective devices, such as shorting switches and grounding hooks, shall be periodically tested to verify their proper operation. Test records shall be maintained by the group/section.

Inspection of Capacitors: All capacitor cans shall be periodically inspected for cracks, leaks, or possible deformity. Should the can display any abnormality, it should be immediately removed from service and tagged as inoperable.

Hazardous Areas: Areas constructed and wired under the terms of Article 500, NFPA 70 shall be inspected at regular intervals to ensure that:

- No live parts are exposed;
- Raceways and enclosures are intact;
- All bonds and grounds are secure;
- All covers, whether bolted or threaded, are in place and intact;
- All openings in boxes and enclosures are closed; and
- All markings are secured and legible.

13.2.18 Training Requirements

All laboratory personnel to be qualified to perform work on electrical devices and systems (low and/or high voltages) shall be trained and competent in all safety related work practices, procedures, and requirements which pertain to their respective work assignments. These skills shall include but are not be limited to:

- Skills and techniques necessary to determine the nominal voltage of exposed live parts;
- Skills and techniques necessary to distinguish exposed energized parts from the other parts of electrical equipment, machines, and processes;
- Knowledge and understanding of the clearance distances required for voltages to which employees could be exposed;

- Proper use of the special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools associated with working on or near exposed parts of electric equipment; and
- Skills and techniques for the understanding of induced and static voltages, grounding integrity, condition of structures, and circuit and equipment location.

All laboratory personnel training to be qualified as a QEW shall work on electrical equipment and systems only when a skilled QEW is present.

All training shall be certified as complete when the employee receives credit for successfully completing the training. Employee training records shall be maintained as long as the staff member is employed by Ames Laboratory (see Section 5).

14.0 REQUIREMENTS FOR SPECIFIC RESEARCH AND DEVELOPMENT (R&D) EQUIPMENT

14.1 Background

R&D electrical equipment and components may pose hazards not commonly found in industrial or commercial facilities. Special precautions are required to design, operate, repair, and maintain this equipment. Electrical safety and personnel safety circuits (e.g., interlocks) are covered in this chapter as a guide to reduce or eliminate associated hazards. Training and experience in the specialized equipment is required to maintain a safe workplace. Nonelectrical hazards are not addressed in this section (see the Ames Laboratory Environment, Safety, Health, and Assurance Program Manual).

14.2 R&D Electrical Equipment Policy

All personnel involved with R&D electrical equipment shall be trained in and be familiar with the hazards they may encounter in the workplace. Only QEWs shall design, install, repair, or maintain electrical research equipment or components. Safety related design, operation, and maintenance techniques shall be incorporated into all new or modified equipment. Existing equipment shall be modified where necessary to ensure safety. Where codes and standards may not exist, sound principles of electrical and personnel safety shall be utilized.

14.2.1 Generic R&D Equipment

There are many possible types of electrical ac and dc power source hazards in complex R&D systems and the various design philosophies preclude establishing hazard classifications based on voltage alone.

14.2.1.1 Power Sources

Hazards:

- Internal component failure can cause excessive voltages. Internal component open-circuit failure in capacitor banks and Marx generators can result in full voltages across components that may not be appropriately discharged in the usual manner.
- Internal component shorts in capacitor banks and Marx generators can result in excessive fault current, causing extreme heat, over pressurization of capacitor cans, and explosion.
- Overloading or improper cooling of power supplies can cause excessive temperature rise.

- Output circuits and components can remain energized after input power is interrupted.
- Auxiliary and control power circuits can remain energized after the main power circuit is interrupted.
- When power supplies serve more than one experiment, errors made when switching between experiments may create hazards to personnel.
- R&D electrical apparatus may contain large amounts of stored energy, requiring fault analysis.
- Liquid coolant leaking from R&D electrical equipment may pose an electrical hazard to personnel.

Design and Construction: In design and construction of R&D equipment, it is important to remember the following cautions:

- Install only components essential to the power supply within the power-supply enclosure.
- Provide appropriate separation between high-voltage components and low-voltage supply and/or control circuits.
- Provide personnel with a visible indicator that the power supply is energized.
- Minimize the number of control stations and provide an emergency shutdown switch where needed.
- Avoid multiple-input power sources where possible.
- Apply a label containing emergency shutdown instructions to equipment that is remotely controlled or unattended while energized.

Operation and Maintenance: Before working in a power-supply enclosure or an associated equipment enclosure, see sections 4, 6 and 8. Personnel should take the following precautions:

- Implement lockout/tagout.
- Check for auxiliary power circuits that could still be energized.
- Inspect automatic shorting devices to verify proper operation.
- Short the power supply from terminal to terminal and terminal to ground with grounding hooks.

14.2.1.2 Conditions of Low Voltage and High Current

Hazards: It is usual for R&D facilities to have equipment that operates at less than 50 V. Although this equipment is generally regarded as nonhazardous, it is considered hazardous when high currents are involved. Examples of such equipment are a power supply rated 3 kA at 25 V, a magnet power supply with rated output of 200 A at 40 V, and a bus bar carrying 1 kA at 5 V.

Though there is a low probability of electric shock at voltages less than 50 V, (see Figure 14-1) there is a hazard due to arcing and heating in case of an accidental fault. For example, a tool could drop onto the terminals and initiate an arc, causing severe burns.

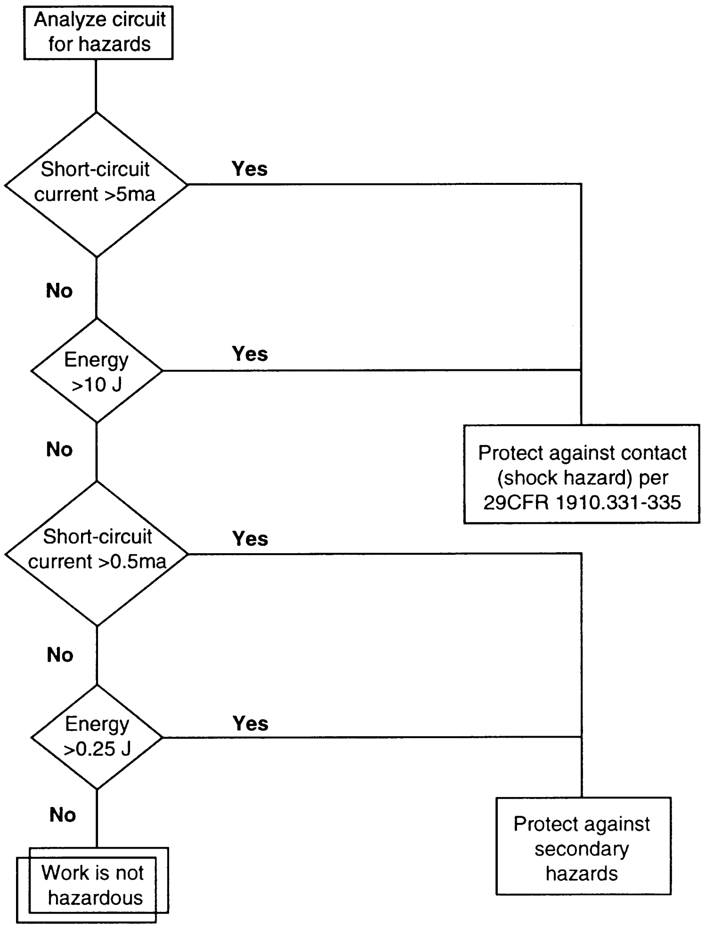
Design and Construction: A circuit operating at 50 V or less shall be treated as a hazardous circuit if the power in it can create electrical shocks, burns, or an explosion due to electric arcs. Inductive circuits may create high-voltage hazards when interrupted. Observe all of the following rules for such circuits:

- Provide protective covers and/or barriers over terminals and other live parts to protect personnel.
- By suitable marking, identify the hazard at the power source and at appropriate places.
- Consider magnetic forces in both normal-operation and short-circuit conditions. Use conductors that have appropriate physical strength and are adequately braced and supported to prevent hazardous movement.

Operation and Maintenance: Follow these guidelines for working on circuits operating at 50 V or less that are treated as hazardous:

- Work on such circuits when they are de-energized.
- If it is essential to work on or near energized low-voltage, high-current circuits, observe the safety rules as if the circuits were operating at more than 50 V. Refer to Sections 6 and 8 of this manual.

Figure 14-1 Process for the Analysis of Circuit Hazards



CIRCUIT HAZARDS

14.2.1.3 Conditions of High Voltage and Low Current

Hazards: When the output current of high-voltage supplies is below 5 mA, the shock hazard to personnel is low. Where combustible atmospheres exist, the hazard of ignition from a spark may exist. High-voltage supplies (ac or dc) can present the following hazards:

- Faults, lightning, or switching transients can cause voltage surges in excess of the normal ratings.
- Internal component failure can cause excessive voltages on external metering circuits and low-voltage auxiliary control circuits.
- Overcurrent protective devices such as fuses and circuit breakers for conventional applications may not adequately limit or interrupt the total inductive energy and fault currents in highly inductive dc systems.
- Stored energy in long cable runs can be an unexpected hazard. Safety instructions should be in place to ensure proper discharge of this energy.
- Secondary hazards such as startle or involuntary reactions from contact with high-voltage low-current systems may result in a fall or entanglement with equipment.

Design Considerations: Personnel in R&D labs may encounter energized parts in a variety of configurations, locations, and under environmental conditions that are not usual for most electrical power personnel. Sometimes the equipment can be designed to incorporate mitigation of the hazards associated with working on such equipment. If not, then safe operating procedures must be developed and used.

Safety Practices: An analysis of high-voltage circuits must be performed by a qualified person before work begins unless all exposed energized parts are guarded as required for high-voltage work (see Section 6.2.6 High Voltage (greater than 600 volts) and Section 4.2.6.1 Insulation/Isolation. The analysis must include fault conditions where circuit current could rise above the nominal rated value as explained here and shown graphically in Figure 14-1. Depending on the results of the analysis, any of the following may apply:

- If the analysis concludes that the current is above 5 mA or energy is above 10 J, then the work is considered to be energized work and must be performed in accordance with Section 6.2.5, Section 6.2.6 and Section 8.
- If the analysis concludes that the current is between 0.5 mA and 5 mA and between 0.25 and 10 J, then the worker may be exposed to a secondary hazard (e.g., startle reaction) that must be mitigated.
- If the analysis concludes that the current is below 0.5 mA and below 0.25 J, then the worker exposure is minimal and no special precautions are required.

High-voltage supplies that use rated connectors and cables where there are no exposed energized parts are not considered hazards. Connections shall not be made or broken with the power supply energized unless they are designed and rated for this type of duty (e.g., load-break elbows). Inspect cables and connectors for damage and do not use if they are damaged. Exposed high-voltage parts must be guarded to avoid accidental contact.

14.2.2 Methods

14.2.2.1 Wiring Methods

Hazard: Unsafe wiring methods can cause electrical injury or fire hazards. R&D work may require the use of wiring methods that are not anticipated in the NEC. These methods may not be consistent with normal commercial and industrial wiring methods, and shall be reviewed by the AHJ for approval.

NEC Article 305 “Temporary Wiring”, requires removal of temporary wiring upon completion of the experiment for which it was installed.

An overly strict interpretation can obstruct the scientific objectives of the R&D configuration, but if a liberal interpretation is allowed, there is a possibility that unsafe wiring methods will be used. The AHJ must consider programmatic needs without sacrificing personnel safety.

Design and Construction:
Design and Construction as an Integral Part of Equipment:
If the AHJ determines that wiring is an integral part of an apparatus (e.g., instrumentation interconnections), then the wiring methods used should be evaluated by the AHJ as providing safe operating conditions. This evaluation may be based on a combination of standards and engineering documentation where appropriate. Such an evaluation should consist of an analysis of all stresses imposed on any electrical conductive elements, including, but not limited to electrical, magnetic, heating, and physical damage potential. The wiring methods selected must mitigate to the greatest practical extent any undesired effects of a failure sequence.

If cable trays are used as mechanical support for experimental circuits, they should be solely dedicated to this use and appropriately labeled. Any such use must be analyzed for detrimental heating effects of the proposed configuration.

Power Supply Interface between Utility Systems and R&D Equipment:
Utility supply voltages should be brought as near to the utilization equipment as possible using NEC-compliant wiring methods.

Any temporary wiring methods used (e.g., extension cords) should be approved by the AHJ for a specified limited time.

Flexible cords and cables should be routed in a manner to minimize tripping hazards.

The conventional use of cable trays is defined in NEC Article 318. If power cables are placed in a cable tray used for control and signal cables, separation shall be provided according to the NEC Article 318. Certain experimental configurations or physical constraints may require the unconventional application of cable trays. Only the AHJ may approve these unconventional applications. If deemed necessary, enhanced fire protection or other safety measures shall be used to ensure safety to personnel and equipment.

For coaxial, heliax and specialty cables used for experimental R&D equipment, where NEC tray-rated cable types are not available which meet the technical requirements of the installation, the non-tray-rated cables shall be permitted with the approval of the AHJ. If deemed necessary, enhanced fire protection or other safety measures shall be used to ensure safety to personnel and equipment.

When metallic cable tray is being used, it must be bonded to the equipment grounding system, but should not be relied upon to provide the equipment ground. The experimental equipment must be appropriately grounded by some other method.

Operation and Maintenance: The operation and maintenance of R&D Systems which use wiring methods that are not anticipated by the NEC require special considerations from all personnel. The AHJ evaluation for safe operating conditions must include a review of unique features in the engineering documentation.

14.2.2.2 Unconventional Practices - Grounding

R&D performed by DOE contractors often incorporates the design of very specialized equipment resulting in the need for specialized grounding and the use of materials and components in an unconventional manner. Even with these experimental needs and special design considerations, the maximum safety of personnel and equipment still needs to be ensured. The practice of using materials or components for purposes other than originally designed needs special consideration in their use, identification, personnel protection, and equipment protection.

Hazards: The lack of proper grounding can cause electrical shock and/or burns to personnel. The NEC and NESC define legally required grounding. To mitigate potential hazards, grounding shall be provided in accordance with the NEC and NESC.

Design and Construction: NEC, Article 250, "Grounding" notes that grounds also provide:

- Voltage limitation in case of lightning, line surges, or unintentional contact with higher voltage lines.
- Stability of voltage to ground under normal operation.
- Facilitated overcurrent device operation in case of ground faults.
- A path to conductive objects that will limit the voltage to ground.

In R&D work there is one additional function for grounds: a common reference plane or system ground return for electronic devices, circuits, and systems (see

DOE Handbook, Electrical Safety, No. DOE-HDBK-1092-2013). It is recognized that such grounds are essential in some cases to control:

- Noise associated with the primary power system including incoming on the line and outgoing from local equipment.
- Ground wire noise.
- Circuit coupling including ground loop (shared circuit return) and magnetic, capacitive or electromagnetic.

Noise Coupling Mechanisms: Grounding can reduce the interference in the five types of coupling mechanisms listed here:

- Conductive Coupling
- Capacitive Coupling
- Inductive Coupling
- System Signal Returns
- Instrumentation Grounding

More technical information is available on Grounding in the DOE Handbook, Electrical Safety, No. DOE-HDBK-1092-2013, July 2013 Research & Development, Grounding.

14.2.2.3 Unconventional Practices - Materials used in an Unconventional Manner

The practice of using materials or components for purposes other than originally designed needs special safety considerations in use, identification, personnel protection, and equipment protection.

Hazards: The use of materials for something other than their original design criteria has the potential for providing an additional hazard, especially to personnel unfamiliar with the research apparatus. Personnel may assume that the material is used as originally designed and can unknowingly expose themselves to hazards unless special precautions are followed.

Some examples of items used in an unconventional manner are:

- Copper pipe used as an electrical conductor
- Insulated flexible copper pipe used as an electrical conductor
- Specially designed high-voltage or high-current connectors
- Specially designed high-voltage or high-current switches
- Water column used as a high-voltage resistor
- Standard coax cable used in special high-voltage pulsed circuits
- Water column used as a charged-particle beam attenuator
- Commercial cable tray used as a mechanical support for experimental apparatus

Design and Construction: During design, special consideration should be given to installing interlocks and protective barriers. Signs warning of the hazards should be posted to help prevent unsuspecting personnel from being injured.

Operation and Maintenance: Appropriate safety procedures and training shall be part of the process to qualify personnel. The procedures should describe the methods used to promote safe work practices relating to work on energized circuits in accordance with sections 6 and 8 as well as 29 CFR 1910.331-335.

14.2.3 Capacitors and Capacitor Banks

This section is particularly applicable to capacitors and capacitor banks used as a source of pulsed power, for blocking and filtering, and in oscillator and resonant circuits where stored energy is generally in excess of 10 joules and terminal-to-terminal or terminal-to-ground voltages exceed 50 volts. Safe work practices shall be used when working with or near capacitors.

Examples of Hazards:

- Capacitors and capacitor banks with stored energy of 10 joules or greater can constitute a shock hazard, and those with stored energy of 25 joules or more can constitute a lethal shock hazard. The actual degree of hazard depends upon the capacitor or capacitor bank voltages in each application.
- Because of the phenomenon of "dielectric absorption," all of the charge in a capacitor is not dissipated when it is short-circuited for a short time.
- A dangerously high voltage can exist across the impedance of a few feet of grounding cable at the moment of contact with a charged capacitor.
- Discharging a capacitor by means of a grounding hook can cause an electric arc at the point of contact.
- Internal faults may rupture capacitor containers.
- Rupture of a capacitor can create a fire hazard. Polychlorinated biphenyl (PCB) and other dielectric fluids can release toxic and/or flammable gases when decomposed by fire or the heat of an electric arc.
- Fuses are generally used to preclude the discharge of energy from a capacitor bank into a faulted individual capacitor. Improperly sized fuses may explode as may the capacitors themselves.
- During transient conditions, capacitors can acquire a charge hazardous to personnel.

Design and Construction Criteria:

- Isolate capacitor banks by elevation, barriers or enclosures to preclude accidental contact with charged terminals, conductors, cases, or support structures.
- Interlock the circuit breakers or switches used to connect power to capacitors.
- Provide capacitors with current-limiting devices.
- Design safety devices to withstand the mechanical forces due to the large currents.
- Provide bleeder resistors on all capacitors not having discharge devices.
- Design the discharge-time-constant of current-limited shorting and grounding devices to be as small as practicable.
- Provide grounding hooks in sufficient number

Operating Criteria:

- Interlocks that may permit personnel to contact energized parts shall not be bypassed except by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.

- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Establish procedures for tagging the interlock, logging its location and the time when bypassed and restored; and require written approvals prior to bypassing an interlock.
- Only QEWs trained in the proper handling and storage of power capacitors and hazard recognition shall be assigned the task of servicing/installing such units.
- Proper personal protection equipment shall be used when working with capacitors.
- Restrict access to capacitor areas until all capacitors have been discharged, shorted, and grounded.
- Remove any residual charge from capacitors by grounding the terminals before servicing or removing.
- Do not rely on automatic discharge and grounding devices.
- Inspect grounding hooks before each use.
- Capacitor cases shall be considered 'charged' until positively grounded by a QEW.
- Periodically test protective devices.
- Short circuit all metal-encased capacitors in storage with a conductor not smaller than #14 AWG.

14.2.4 Electrical Conductors and Connectors

The conductors and connectors covered in this section are those used in special research activities and include high-current (pulsed or continuous), high-voltage, high-frequency, liquid-cooled, and other special conductor and connector applications. All conductors and connectors shall be of an approved type, and shall be designed for the application intended.

Examples of Hazards:

- Hazards can occur due to conductor insulation damage or deterioration.
- Metallic cooling-water pipes that are also used as electrical conductors present shock hazards.
- Improper application or installation of connectors can result in overheating, arcing, and shock hazards.
- Hazardous induced voltages and arcing can result from inadequate separation between high and low voltage cables.
- Shock hazards can result from ungrounded or improperly grounded shields.

Design and Construction Criteria:

- Provide conductors adequate for voltage levels involved and for current capacities.
- Select conductor insulation that is appropriate for the operating and environmental conditions.
- Where liquid- or gas-cooled conductors are used, a fail-safe, automatic shutdown is needed if the cooling system malfunctions.
- Avoid conductor loops.
- Provide suitable physical protection for coaxial cables used in pulsed-power applications.

- Provide physical barriers to separate high-voltage conductors from low-voltage conductors and/or terminations.

- Provide adequate labeling, insulation or other protection for metallic cooling-water piping used as electrical conductors.
- Provide bracing and conductor supports for expected mechanical forces and voltages.
- Provide approved and properly rated connectors.
- Provide connectors appropriate for use with the conductor metal composition.
- Avoid cold solder joints and loose connections.

Operating Criteria:

- Reusable cables shall be carefully handled and stored between uses.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Prohibit walking on cables or climbing on cable trays.
- Laying cables across the floor for experimental work shall be prohibited.
- Cable connectors shall be checked and adjusted periodically.
- Plug-in cable connectors, particularly for high voltages or high currents, shall be mechanically fastened in place. The power source shall be de-energized before removing a connector. All cables and connectors shall be checked for integrity prior to use.
- Coaxial cable shielding shall be securely grounded as required.

14.2.5 Enclosures for Electrical Equipment

This section is particularly applicable to enclosures where equipment voltages exceed 50 volts to ground and where enclosures contain RF radiation or stored-energy electrical components. All metal enclosures shall be grounded. Nonmetallic enclosures shall be of a type approved for the intended use. Design of nonmetallic enclosures that have not been approved by an NRTL shall be approved by the AHJ before fabrication.

Examples of Hazards:

- Ungrounded or poorly grounded enclosures may result in electrical shock hazard.
- RF, eddy current and microwave heating, electrical arcing, and molten metal (with inadequate enclosures) may cause burns.
- Faults occurring inside the enclosure may rupture the enclosure and injure personnel or damage adjacent equipment.
- Failure of interlocks may permit personnel to contact energized equipment within an enclosure.
- Crowded work conditions within enclosures.

Design and Construction Criteria:

- Design enclosures with adequate space, so that no contact with live electrical parts can be made from the outside.
- Provide electrical interlocks on all easily accessible doors and panels of enclosures which contain hazardous exposed voltages.
- Provide separate functional compartments (e.g., low-high voltage, control).
- Provide properly shielded and grounded enclosures.

- Provide structurally adequate enclosures.

Operating Criteria

- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored; also provide for written approvals prior to bypassing an interlock.
- Notify all affected personnel before energizing the equipment.
- Post suitable warnings to indicate equipment hazards.

14.2.6 Inductors, Electromagnets and Coils

This section covers inductors, electromagnets and coils that are used in the following typical applications:

- Energy storage;
- Inductors used as impedance devices in a pulsed system with capacitors;
- Electromagnets and coils that produce magnetic fields to guide or confine charged particles;
- Inductors used in dc power supplies; and
- Nuclear Magnetic Resonance (NMR), Electron Paramagnetic Resonance (EPR), and Magnetic Susceptibility Systems.

Examples of Hazards:

- Superconductive magnets may produce external force fields
- Whenever a magnet is suddenly de-energized, production of large eddy currents in adjacent conductive material may cause excessive heating and voltages
- Magnetic forces from inductors
- Inappropriate discharge of a large amount of energy stored in the magnetic field may cause injury to personnel
- Large amounts of stored energy can be released in the event of a "quench" in a super conducting magnet

Design and Construction Criteria:

- Provide sensing devices (temperature, coolant-flow) which are interlocked with the power source.
- Fabricate protective barriers from materials not adversely affected by external magnetic fields. Researchers should consider building a nonferrous barrier designed to prevent accidental attraction of iron objects and prevent damage to the cryostat. This is especially important for superconducting magnet systems.
- Provide equipment supports and bracing adequate to withstand the forces generated.
- Appropriately ground electrical supply circuits and magnetic cores and provide adequate fault protection.
- Provide means for safely dissipating stored energy when excitation is interrupted or a fault occurs.

- Post warning signs reading, "CAUTION - MAGNETIC FIELD - KEEP MAGNETIC MATERIALS OUTSIDE BARRIER", in a conspicuous location for iron core magnet coil and superconducting solenoid systems capable of containing electrical energy in excess of 50 joules, or which carry currents greater than 1,000 amperes, or which produce fields of 0.5 Tesla or more.

Operating Criteria:

- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- Provide suitable warning to indicate equipment hazards.
- Advise personnel of the hazards of stray magnetic fields.
- Verify that any large inductor is de-energized before disconnecting the leads or checking continuity or resistance.

Static Magnetic Fields:

The Ames Laboratory follows the American Conference of Government and Industrial Hygienists (ACGIH) Guide for exposure to static magnetic fields. These threshold limit values (TLVs) refer to static magnetic flux densities to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. These values should be used as guides in the control of exposure to static magnetic fields and should not be regarded as fine lines between safe and dangerous levels.

Routine occupational exposures should not exceed 60 milli-tesla (mT), equivalent to 600 gauss (G), whole body or 600 mT (6000 G) to the limbs on a daily, time-weighted average basis [1 tesla (T) = 10^4 G]. Recommended ceiling values are 2 T for the whole body and 5 T for the limbs. Safety hazards may exist from the mechanical forces exerted by the magnetic field upon ferromagnetic tools and medical implants. Cardiac pacemaker and similar medical electronic device wearers should not be exposed to field levels exceeding 0.5 mT (5 G). Adverse effects may also be produced at higher flux densities resulting from forces upon other implanted devices such as suture staples, aneurism clips, prostheses, etc.

14.2.7 Induction and Dielectric (RF/Microwave) Heating Equipment

This section describes electrical hazards associated with induction heating, RF equipment, and microwave equipment used in research. The hazards are mainly associated with the high power/high frequency RF generators, waveguides and conductors, and the working coils producing temperatures as high as 3000° C.

Examples of Hazards:

- RF power as high as 50 kW and frequency in tens of kHz to hundreds of MHz, are supplied from RF and microwave generators. Being close to, or making contact with an unprotected coil, conductor or waveguide opening may result in severe body burns.
- Dangerous voltages are present inside the power generators.
- Dangerous levels of RF energy may be present in the laboratory.
- Wet areas (conductive) caused by cooling-water leaks can create a shock hazard.

Design and Construction Criteria:

- The RF/microwave generators shall be installed in a grounded and interlocked cabinet which disables operation when the protective barriers are open.
- The heating coils, sources of high frequency energy, and other live parts outside of the generator cabinet shall be shielded or guarded to prevent access or contact.
- The heating coil shall have its cold (outside) lead properly grounded.
- A coaxial cable of correct impedance and adequate construction shall be used to deliver the RF power to the coil without leakage of the RF energy to the laboratory work space.
- All safety circuits, breakers, and interlocks shall be designed for safe and reliable operation.
- A warning light which indicates when the equipment is in use shall be installed.

Operating Criteria:

- All systems shall be inspected for hazards before operation.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.
- Procedures shall be established for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- All operators shall be trained in the safe use of the equipment.
- No shields shall be removed during the operation of the induction heating equipment without following proper procedures.
- Shielding shall be maintained to minimize RF/microwave radiation.
- Wearing metallic objects near high frequency power sources is prohibited.
- Post suitable warnings to indicate equipment hazards.

14.2.8 Instrumentation and Control Systems

This section covers interconnection of instrumentation and control systems that are associated with R&D equipment and operation.

Examples of Hazards:

- Instrumentation and control systems may involve circuits which operate at hazardous voltage levels (e.g., greater than 50 volts) and/or which are supplied from low-voltage, high-current power supplies.
- Failure of insulating and/or isolating devices could bring systems in contact with hazardous voltages or currents.
- Failure or malfunction of circuitry can produce hazardous conditions.
- Failure of control circuits can cause unintentional operation of hazardous equipment.

Design and Construction Criteria:

- Provide electrical instrumentation and control circuitry with adequate isolation at its interface with the main power equipment being controlled and monitored.
- Assure that relay and interlock contacts on instrumentation and protective circuits are sufficiently rated.
- Design control circuits using fail-safe techniques where applicable.
- Provide redundant controls and instrumentation where hazards warrant.
- Provide a clear indication of the status of hazardous remotely controlled equipment.
- Properly label or cover exposed terminals where voltages of 50 volts or more may be present.
- Provide separate raceways or physical isolation between instrumentation cabling, high-current conductors, and unguarded conductors above 600 volts.
- Use consistent labeling.
- Design protective interlock circuits to prevent automatic restoration of system operation.

Operating Criteria:

- Carefully inspect and test all new or modified instrumentation and control systems.
- Correct malfunctions or failures of instrumentation and control systems before returning the system to operation.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.

14.2.9 Lasers

This section is applicable to CLASS 3B and CLASS 4 laser systems used in research.

Both fixed and portable equipment are covered regardless of input voltage. Nonelectrical hazards are not addressed in this section. For nonelectrical hazards refer to the Ames Laboratory Environment, Safety, Health and Assurance Program Manual.

Examples of Hazards:

- Dangerous voltages are present inside the equipment.
- Vacuum implosion hazards may exist with the laser covers removed.
- Energy storage devices may present a hazard due to a residual charge even with the power removed.
- Dangerous voltages can exist across the impedance of the grounding conductor during laser pulses.
- Leaking liquid coolant can create a shock hazard.
- Failure of interlocks and safety devices may allow access to energized parts.

Design and Construction Criteria:

- Engineered safety systems including interlock and shutter safety systems shall be designed, fabricated, and installed by a certified manufacturer utilizing NRTL equipment.
- Operator intervention shall be required to open the beam shutter or reactivate the laser after interlock or safety system operation.
- All safety circuits or equipment shall be designed for safe and reliable operation.
- All hazardous parts shall be enclosed and grounded to prevent inadvertent contact.

Operating Criteria:

- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- Only QEWs shall repair or perform maintenance on laser electrical equipment.
- Only FES and/or the certified manufacturer shall repair or perform maintenance on laser interlock systems.
- Before repair or maintenance is performed, all power sources shall be disconnected, properly locked out/tagged out, and energy storage devices shall be discharged and their de-energized condition verified. Refer to the Ames Laboratory Environment, Safety, Health and Assurance Program Manual.
- Proper personal protective equipment shall be worn as outlined in Section 12.2 of this manual. Special laser glasses or goggles may be required.
- Repair work or adjustment requiring the disabling of protective interlock systems or removal of protective enclosures, shall be approved per the Administrative Control section of this manual.
- Ensure that all grounding wires used during repair and maintenance are removed before operation of the laser is resumed.

- FES shall test the safety systems at least as often as recommended by the manufacturer, designer or at least annually and maintain a log on repairs and testing.
- Groups/sections shall control issuance of the bypass keys for interlock/shutter safety systems.
- When protective panels are removed, the system high voltage capacitors must be discharged using appropriate grounding hooks.
- All operators shall be trained to be aware of the electrical hazards involved with laser operation.
- Before laser operation begins, assure that all covers are in place and that no interlocks or safety systems have been disabled.
- Keep all conductive or corrosive liquids away from electrical equipment.

14.2.10 Power Supplies

This section is particularly applicable to high-voltage (over 600 volts terminal-to terminal or 300 volts-to-ground) ac or dc power supplies and low-voltage, high-current ac or dc power supplies used in special R&D activities. This section is also applicable to other types of power supplies where the hazards identified herein may also exist.

Examples of Hazards

- Electrical faults or switching transients can cause voltage surges.
- Internal component failure can cause excessive voltages.
- Overloading or improper cooling of power supplies can cause excessive temperature rise.
- Electrical faults can cause numerous failures to internal components.
- Output circuits and components can remain energized after input power is interrupted.
- Auxiliary and control power circuits can remain energized after the main power circuit is interrupted.
- When power supplies serve more than one experiment, errors made when switching between experiments can create hazards to nearby personnel.
- Overcurrent protective devices may not adequately limit or interrupt the total inductive energy and fault currents.

Design and Construction Criteria:

- Only components essential to the power supply should be installed within the power-supply enclosure.
- Provide isolation devices or physical barriers between high-voltage components and low-voltage supply and/or control circuits.
- Provide isolation devices or physical barriers to prevent accidental contact.
- Provide automatic discharging of the power supply when the input power is turned off.
- Provide overcurrent, under voltage, or other protection for both power supply and load as appropriate.
- Clearly identify the main power input disconnect for each power supply.
- Provide a visible indicator to personnel that the power supply is energized
- Minimize the number of control stations and provide an emergency shutdown switch where needed.

- Avoid multiple-input power sources.

Operating Criteria:

- Initially inspect the power supply and calibrate and check all its protective devices.
- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section leader.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- Before working in a power-supply or associated equipment enclosure, take the following precautions:
    - De-energize the equipment.
    - Open and lockout/tagout the main input-power circuit breaker.
    - Check for auxiliary power circuits which could still be energized.
    - Inspect automatic shorting devices to verify proper operation.
    - Short the power supply from terminal-to-terminal and terminal-to-ground with grounding hooks.
    - Label the equipment to identify the input power sources.
    - Label energized equipment that is remotely controlled or unattended with emergency shutdown instructions.

14.2.11 Switches-Electrical

This section covers special electrical switches used in R&D activities where safety requirements are not specifically covered by existing codes.

Examples of Hazards:

- Inadvertent contact with energized parts may cause electrical shock.
- Sufficient energy may cause the switch to explode.
- Loose switch terminals may cause arcing.
- Electrically controlled switches operated unintentionally may present shock hazards.
- Switches opened under load conditions may create severe arcing.
- Underrated switches may cause shocks or other electrical hazards.

Design and Construction Criteria:

- Interrupting ratings of switches shall exceed worst case load and fault conditions.
- Provide a positive indication of switch positions.
- Provide a system to control power interlocks for use during testing or maintenance periods as required.
- Provide locking features on switches where needed.
- Assure that switches not designed to disconnect under load conditions cannot be opened when the circuit is energized.

- Provide protective covers and/or barriers.
- Provide suitable means for maintaining secondary isolating and/or transfer-type switches in the desired position.

Operating Criteria:
- Utilize proper lockout/tagout procedures before working on connected circuits or equipment.
- Establish and implement safe operating procedures.
- Inspect switch conditions and perform operating tests at least as often as recommended by the manufacturer, designer or at least annually.

14.2.12 Uninterruptible Power Systems and Batteries

This section covers Uninterruptible Power Systems (UPS) and rechargeable-type batteries used for storage of electrical energy. These criteria are generally intended for batteries with a 10AH rating or greater. This section is not limited to systems or batteries of a particular voltage and energy rating, since the nature of the associated electrical hazards is similar for any system or battery size, except that the severity of the hazard increases with increased output rating.

Examples of Hazards:
- Accidental grounding of one polarity of a battery bank can create a hazardous voltage between the ungrounded polarity and ground.
- Shorting of the exposed terminals or cables of a battery can result in severe electric arcing, causing burns and electrical shock to nearby personnel.
- Hydrogen gas generated during battery charging can create fire and explosion hazards.
- Exposed terminals of a battery bank present electrical shock hazards.
- Batteries may explode if shorted or if overcharged.
- Electrolytes may be highly corrosive and can produce severe burns.
- A UPS may produce energy after building power has been disconnected, creating a hazard to workers unaware of the danger.

Design and Construction Criteria:
- UPS and battery installations shall conform to requirements in the latest edition of the National Electrical Code (NEC).
- Battery banks should not be grounded. A ground detector should be used to indicate an accidental ground.
- Mount batteries so as to allow safe and convenient access for maintenance.
- Provide lockable doors to rooms or enclosures containing battery banks.
- Provide deluge safety showers and eye-wash stations near battery banks.
- Exhaust systems shall be installed where necessary to minimize the risk of hazardous and toxic fume accumulation.
- Facilities for neutralizing spilled electrolytes and fire protection shall be provided.

Operating Criteria:
- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.

- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section.
- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- Maintain clean and tight battery-bank connections (cell-to-cell and terminal).
- Do not repair battery connections when current is flowing.
- Post clearly visible signage warning of electrical and other hazards for battery banks.
- Only insulated tools shall be used working on or near exposed battery terminals.
- Workers shall wear personal protective equipment when handling electrolytes.
- All persons working in the area shall be trained in the hazards involved.
- UPS shall be maintained to prevent the accumulation of dust, and shall be provided with the required clear working space.
- UPS and batteries shall be tested and maintained for safe and reliable operation at least annually.

14.2.13 X-ray Equipment

This section is applicable to all x-ray equipment used in research. For nonelectrical hazards refer to the Ames Laboratory Environment, Safety, Health and Assurance Program Manual.

Examples of Hazards:

- Dangerous voltages are present inside equipment.
- Failure of interlocks and safety devices may allow access to energized parts and expose workers to x-ray hazards.
- Leaking liquid coolant can create a shock hazard.
- Energy storage devices may present a hazard due to a residual charge even with the input power removed.

Design and Construction:

- Engineered safety systems including interlock and shutter safety systems shall be designed, fabricated, and installed by FES and/or a certified manufacturer utilizing NRTL equipment.
- Operator intervention shall be required to open the beam shutter or reactivate the x-ray unit after interlock or safety system operation.
- All safety circuits and equipment shall demonstrate safe and reliable operation.
- X-ray shutters shall be equipped with a red light warning of an open shutter.
- The shutter and the shutter-open indicator light shall provide fail safe operation.
- A log shall be maintained to record all repairs and maintenance.
- All hazardous parts shall be enclosed and grounded to prevent inadvertent contact.
- Group/Section shall control issuance of the bypass keys for their interlock/shutter safety systems.

Operating Criteria:

- Interlocks shall not be bypassed, unless by QEWs when inspecting, adjusting, or working on the equipment. Proper procedures shall be followed when bypassing interlocks. Always remove the bypass when inspections, adjustments, or maintenance work has been completed.

- Establish procedures for tagging the interlock and logging its location and the time when bypassed and restored, and require written approvals prior to bypassing an interlock.
- All safety circuits and interlocks shall be tested for safe operation at least as often as recommended by the manufacturer, designer or at least annually. Test documentation must be maintained by the group/section.
- Only the FES and/or the certified manufacturer shall repair or perform maintenance on x-ray interlock systems.
- Only QEWs shall repair or perform maintenance on x-ray equipment.
- All energy storage devices shall be discharged, and their de-energized condition shall be verified before repair or maintenance.
- Ensure that all grounding wires used during repair and maintenance are removed before operation of the equipment is resumed.
- All operators shall be trained to be aware of the electrical hazards involved with x-ray operation.
- Assure that all covers are in place and that no interlocks or safety systems have been disabled before resuming operation of the equipment.
- Keep all conductive or corrosive liquids away from electrical equipment.

14.2.14 Arc Melting and Other Similar R&D Equipment

This section covers Arc Zone Refiners and similar R&D equipment employing power supply voltages listed below which are used for the preparation of metals and alloys. The requirements of this section apply for operating voltages of 50 volts or less with open circuit voltages of 100VDC or 80VAC or less. These requirements shall be applied to all subject equipment both existing and new.

New equipment covered by these procedures shall be inspected by the Certified Ames Laboratory Electrical Inspector for proper compliance before this equipment is placed into operation. This is required even when the equipment is part of an existing activity which was previously subjected to a Readiness Review and which had previously been granted operational approval.

Examples of Hazards:

- Arcing from accidental contact by conductive objects (tools, jewelry, etc.) can generate heat causing burns, flash burns, and molten metal splashing in the immediate area of the contact point.
- Electric shock, particularly when arc-generating high frequency voltages are present, can occur.

Design and Construction Criteria:

- Power is derived from power supplies of the type normally used for arc welding.
- The output of the power supply shall be floating in respect to ground.
- The material used for insulating conductive parts shall be suitable for the electrical and environmental conditions.
- In order to prevent accidental contact with tools or other conductive objects, the electrode supply conductors, their associated connections and energized

conductive surfaces shall be appropriately insulated or isolated from each other. Conductive parts must be covered with durable insulating material (suitable for the electrical and environmental conditions) or have an isolated section to achieve a barrier. Isolated sections shall be properly grounded. A distance of at least 8” measured from the point nearest to the two different electrode potentials is required for insulating material or isolated section.

- Figures 14-2 and 14-3 show typical arc melting equipment with required insulation or grounded isolated sections.
- Any part of the chamber or movable electrode that an operator must grip or rest their arms on shall be equipped with insulating pads or handles.

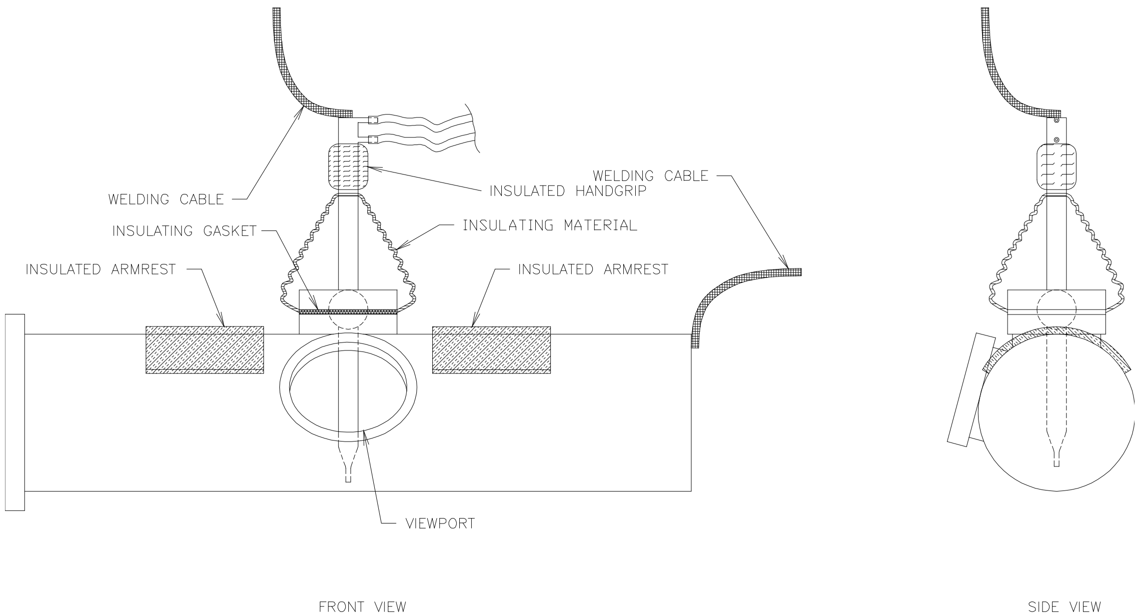


FIGURE 14-2A ARC MELTER WITH INSULATING MATERIAL AROUND ELECTRODE

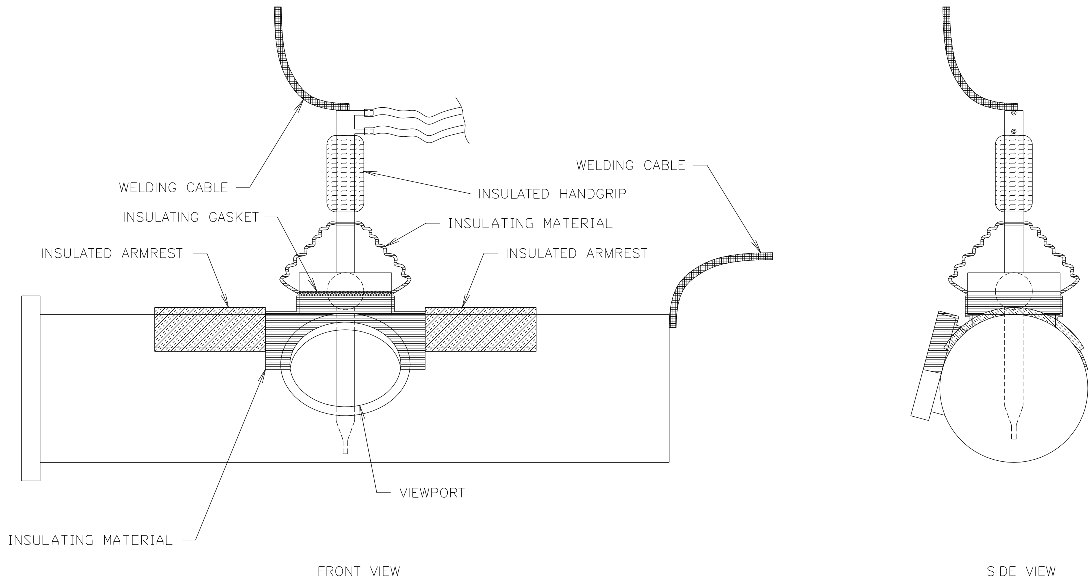


FIGURE 14-2B ARC MELTER WITH INSULATING MATERIAL AROUND ELECTRODE AND VESSEL

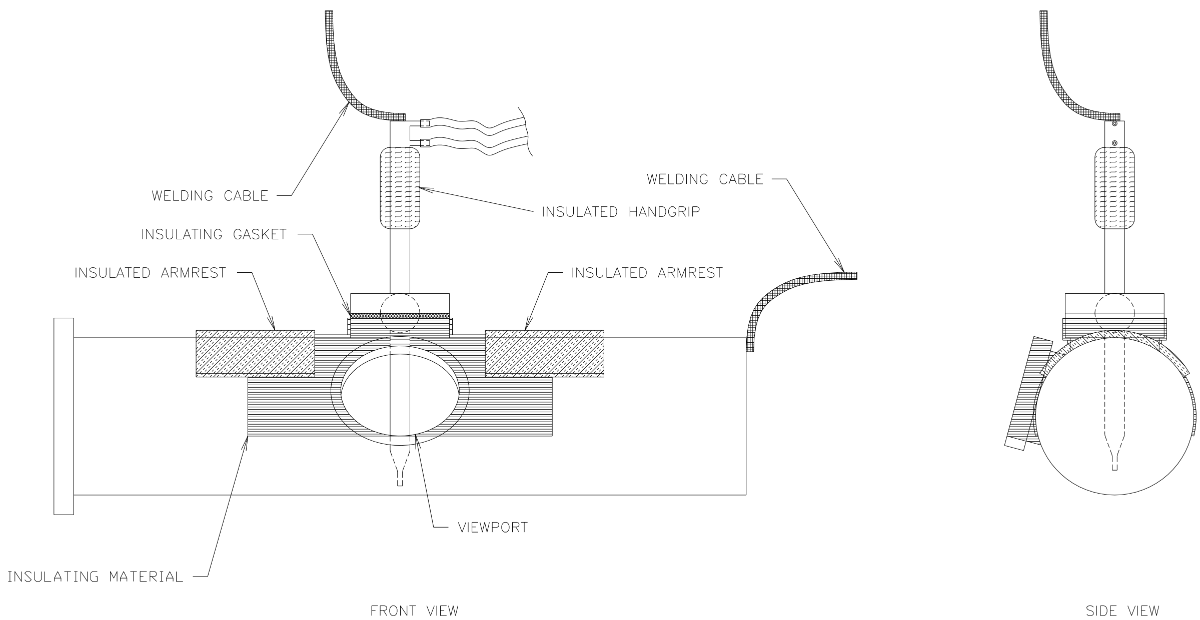


FIGURE 14-2C ARC MELTER WITH INSULATING MATERIAL AROUND VESSEL

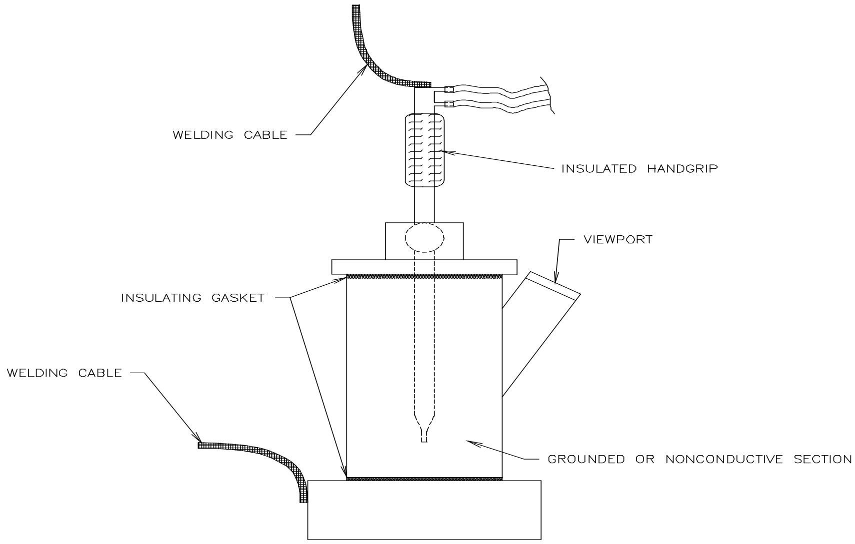


FIGURE 14-3 ARC MELTER WITH GROUNDED ISOLATED SECTION

Operating Criteria:

- Insulating barriers shall not be removed during operation of equipment.
- Utilize proper lockout/tagout procedures before working on the equipment.
- Dismantling and reassembly of equipment shall be carefully performed to ensure all electrical isolation and grounding systems remain fully functional.

14.2.15 Motors, Motor Switches and Power Cords

Electric motors of 1/3 horse power or less may be controlled by inserting or removing the power cord plug from an appropriate receptacle. A switch is not required. (See the cord size table (Table 14-1) for correct cord size.) Motors, motor switches and power cords shall meet the requirements of NEC 430.

Motors: All electric motors which are not protected by external overload sensing devices (i.e., designed protection to codes and standards via a thermal current overload sensor) shall be protected by an internal thermal switch which is an integral part of the motor manufacture or by impedance protection inherent in the motor design and manufacture.

Motor Switches: Electric motors over 1/3 horse power must be controlled by an appropriate switch or controller. They should not be plugged in with the switch on or unplugged while running. An appropriate switch is one that meets the following requirements:

- Has been listed or recognized by UL or CSA.
- Is designed for motor control use.
- Has a voltage rating equal to or greater than the voltage source.
- Has a current rating equal to or greater than 125% of the motor current.
- Has a horse power rating equal to or greater than the motor it is controlling.

All switches are marked with the above ratings. The switch must be properly installed in an approved metal box or enclosure with a strain relief connector for the power cord.

*Power Cords***:** Power cords must be sized for the load and constructed of materials that will withstand the environment they will be used in. Table 14-1 lists recommended cord sizes for motor loads. All power cords must be approved and include a grounding conductor which shall be firmly attached to the motor frame.

All flexible cords are marked with the wire size. These markings may be difficult to read. Under sized or defective cords and plugs can sometimes be detected by touch. If they are warm or hot they should be taken out of service immediately. Always look for bad insulation before touching.

Outlet power strips are not designed for the high starting currents of motors and should not be used. Extension cords are for temporary use only. In most cases, longer power cords up to 15 feet may be installed if necessary.

Table 14-1 Allowable Ampacity for Flexible Cords and Cables+
[Based on Ambient Temperature of 30°C (86°F)]

Size AWG	Thermoset Type TS	Thermoset Types C, E, EO, PD, S, SJ, SJO, SJOO, SO, SOO, SP-1, SP-2, SP-3, SRD, SV, SVO, SVOO	
	Thermo-plastic Types TPT, TST	Thermoplastic Types ET, ETLB, ETP, ETT, SE, SEO, SJE, SJEO, SJT, SJTO, SJTOO, SPE-1, SPE-2, SPE-3, SPT-1, SPT-2, SPT-3, ST, SRDE, SRDT, STO, STOO, SVE, SVEO, SVT, SVTO, SVTOO	
		A*	B*
18		7	10
16		10	13
14		15	18
12		20	25
10		25	30
		Above 30 AMPS - consult Facilities Services Group	

+ This Table is similar to NEC 400-5

* The allowable currents under subheading A apply to 3-conductor cords and other multi-conductor cords connected to utilization equipment so that only 3 conductors are current carrying. The allowable currents under subheading B apply to 2-conductor cords and other multi-conductor cords connected to utilization equipment so that only 2 conductors are current carrying.

15.0 REQUIREMENTS FOR SPECIFIC BUILDING EQUIPMENT

15.1 Background

Various types of electrical equipment utilized in facilities have special electrical safety requirements. Many of these requirements are incorporated during the design and installation process; however, they are related to continuing activities such as maintenance and fire protection.

15.2 Requirements for Specific Building Equipment Policy

Personnel working on or near specific building equipment shall be trained in and familiar with the electrical hazards which may be associated with such equipment. Applicable codes, standards, and manufacturer's recommendations shall be followed to ensure personnel safety during the operation, maintenance, and repair of equipment.

15.2.1 Cranes and Hoists

Electrical Safety: The most significant factor in crane safety, after structural integrity, is electrical safety. All of the referenced standards support this fact either directly or indirectly by the amount of definition and detail provided for electrical systems' controls, operations, and maintenance.

National Electrical Code (NEC) General Requirements: The basic installation and wiring safety requirements for cranes are given in *NEC Article 610*. Electrical designers and maintenance personnel should thoroughly understand these requirements and implement their intent.

Disconnecting Means: Disconnecting means shall be provided for cranes and hoists in accordance with *Article 610, Part D, Disconnecting Means, of the NEC*. The means of disconnect must be provided for runway conductors (*NEC Section 610-31)* and the crane or hoist (*NEC Section 610-32)*. Hard wired disconnects shall be clearly labeled. The installation and operating plans should be clearly understood prior to operation or maintenance of the equipment.

Grounding: All conductive component parts of the crane or hoist shall be bonded together so that the entire crane or hoist is grounded in compliance with *NEC Article 250, Part G*, and *NEC Section 610-61*. Metal-to-metal contact is required between all surfaces, including the trolley wheels and bridge. If any such surfaces are painted or otherwise insulated, a separate bonding conductor is required.

The bonding of all conductive surfaces by metal-to-metal contact shall not be considered the equipment grounding conductor for the electrical equipment on the crane or hoist. All noncurrent-carrying metal parts of electrical equipment shall have equipment grounding conductors sized in accordance with *NEC Article 250, Part G*.

Control: A limit switch is required to prevent the load block from passing the safe upper travel limit on all hoisting mechanisms per *NEC Section 610-55*.

Clearances: The working space clearance in the direction of live parts is 2 1/2 feet, and doors enclosing live parts that may require service or maintenance shall open at least 90 degrees or be removable per *NEC Section 610-57*.

OSHA Requirements: Additional electrical requirements (*29 CFR 1910.179* and *NEC Article 610, Part F*) are provided by and derived from ANSI and other standards. Significant requirements are:

- ***Voltages:*** Control circuit voltage shall not exceed 600 V ac or dc. Pendant pushbutton voltage shall not exceed 150VAC or 300VDC. 120 V shall be used if possible per DOE Orders 6430.1 and 1640.2.5.
- ***Cable Support:*** Support shall be provided for pendant multi-conductor cables.
- ***Failsafe Operation:*** Electrical systems for cranes and hoists shall provide failsafe operation.

Maintenance and Operations: Every electrical part and circuit must be checked and serviced at the frequency and as specified by OSHA, CMAA, ANSI, and the manufacturers manual. Required periodic tests and required record keeping are contained in ANSI B-30 and CMAA documents. The basic references for safe operation and maintenance of cranes and hoists are contained in *29 CFR 1910* and *1926*.

Documented Maintenance: Maintenance checklists and schedules in compliance with OSHA, the owner's manuals, and the manufacturer's recommended requirements for the specific equipment shall be provided as required. Periodic inspections shall be conducted and comments and condition of the inspected part shall be documented and certified as required by *29 CFR 1910.179.*

15.2.2 Elevators

Codes and Standards: All elevators shall be constructed, installed, and maintained in accordance with *ASME/ANSI A17.1*. Reference standards include *NFPA 70 (NEC)* for the electrical equipment wiring and *NFPA 101 (Life Safety Code)*, Chapters 7, 8, and 9. These standards reflect the interrelated roles of electrical design, maintenance, and fire protection in elevator safety.

Authority Having Jurisdiction (AHJ): The Authority Having Jurisdiction (AHJ) for elevators is the State of Iowa, Iowa Workforce Development, Division of Labor Services, Elevator Safety (State Elevator Inspector) in accordance with the State Elevator Code. Inspections and operating permits will be obtained for the AHJ.

Inspections and Records: Elevator inspections and record keeping shall be performed in accordance with State Elevator Code.

15.2.3 Motors

Installation and maintenance of motors shall be provided by qualified electricians in accordance with the requirements of *Article 430 of the NEC.*

15.2.4 Capacitors and Capacitor Banks

A capacitor bank is used for power factor correction on the electrical service. Special precautions must be taken when working on or near these capacitors to control the hazards involved with stored energy.

15.2.5 Emergency/Standby Systems

The installation, maintenance and documentation of Uninterruptible Power Systems (UPS) and generators sets shall meet the requirements of *Articles 700, 701, and 702* of the *NEC.* For R&D equipment refer to the Requirements for Specific R&D Equipment of this manual.

Appendix A
Definitions and Acronyms

DEFINITIONS

ACCEPTED: Certified, listed, labeled, approved or otherwise determined to be safe by a Nationally Recognized Testing Laboratory (NRTL) such as, but not limited to, Underwriters Laboratories, Inc. and Factory Mutual Engineering Corp., or by the Authority Having Jurisdiction (AHJ).

ACCESSIBLE: Allowing close approach; not guarded by locked doors, elevation, or other effective means.

ACTIVITY SUPERVISOR (KNOWLEDGEABLE PERSON OR DESIGNEE): One who is recognized by laboratory management as having a sufficient understanding of an experimental device or facility (i.e., the activity) to be able to positively identify and control the hazards it could present.

AFFECTED EMPLOYEE (AFFECTED PERSONNEL): An employee whose job includes activities such as, erecting, installing, constructing, repairing, adjusting, inspecting, operating, servicing, or maintaining the equipment or process from a non-electrical perspective.

AFFECTED VISITOR (AFFECTED PEOPLE OR GENERAL PUBLIC): Employees as well as visitors (general public) who are in the area and might be affected by the servicing, operation or maintenance of equipment.

AMES LABORATORY TRAINING RECORDS DATABASE (ALTRS): The Ames Laboratory Training Records Database is utilized to track institutional training modules. It provides a record of each employee's completed training to date, while also identifying any modules with a "pending status". The system also tracks all active and inactive modules and has the capability of generating multiple training reports.

APPROVED: (See Accepted)

APPROVED STANDARD OPERATING PROCEDURE: This procedure shall be written by the group/department to cover ongoing routine electrical energized work. The Electrical Safety Committee and ESH&A shall approve it before work is started.

AUTHORITY HAVING JURISDICTION (AHJ): The Ames Laboratory Electrical Safety Committee shall be the Authority Having Jurisdiction (AHJ) having sufficient expertise in electrical safety to be the electrical authority at this facility.

AUTHORIZED PERSONNEL (AUTHORIZED PERSON): A person to whom the authority and responsibility to perform a specific assignment has been given by the employer, and who can demonstrate by experience and/or training the ability to recognize potentially hazardous electrical energy and its potential impact on work place conditions. The authorized person has the knowledge to implement adequate methods and means for the control and isolation of such energy. Authorized personnel could include those not-qualified but having a need to be in a restricted area to perform a specific task such as supervisors, electrical engineers, electricians, mechanics, operators, custodians, and painters (the latter case results in authorized personnel also becoming affected employees).

BACK-UP PROTECTION: A secondary, redundant, protective system provided to de-energize a facility to permit safe physical contact by personnel. This system shall be totally independent of the first-line protection and shall be capable of functioning in the event of total failure of the first-line protective system.

BARRICADE: A physical obstruction such as tapes, ropes, cones or A-frame type or metal structures intended to provide a warning about, and to limit access to, a hazardous area.

BARRIER: A physical obstruction which is intended to prevent contact with energized lines or equipment and/or prevent unauthorized access to a work area.

BOND: The electrical interconnection of conductive parts intended to maintain a common electrical potential.

BUS: A conductor or group of conductors that serve as a common connection for two or more circuits.

CABLE TRAY: A unit or assembly of units or sections and associated fittings, forming a rigid structural system used to support cables. This includes ladders, troughs, channels, solid bottom trays, and other similar structures. Cable trays are not considered raceways.

CERTIFIED: (See Accepted)

CIRCUIT: A conductor or system of conductors through which an electric current is intended to flows.

CLEARANCE (FOR HAZARD): Dimensional separation from energized or potentially energized conductors and/or exposed electrical equipment.

- **EMPLOYEE MINIMUM WORK DISTANCE (CLEARANCE):** The minimum permissible separation distance between the employee (in this case, always a qualified electrical worker), or any conducting object contacting the employee, and an energized component.

- **SYSTEM CLEARANCE DISTANCE:** Mandatory separation distance between energized lines or components and a vehicle, machine, load, etc. These requirements are generally stated in Federal regulations.

- **TRAVELING CLEARANCE:** The minimum overhead distance for machinery or vehicles in motion traveling under electrical lines, or for components with booms, elevated parts, dump bodies, etc., secured in the down position.

- **WORKING CLEARANCE:** The minimum overhead distance for machinery, vehicles, etc., working or otherwise in the vicinity of electrical lines, etc., when not traveling.

CLEARANCE (FOR WORK): Authorization to perform specified work or permission to enter a restricted area (not security related).

COMMON LOCKOUT SYSTEM: A system which permits the use of locking devices not considered unique or uniquely controlled.

COMPANION: A co-worker (who is normally also a QEW) who is cognizant of the danger and regularly checks on the other worker.

CONDUCTOR: A material capable of carrying electric current usually in the form of a wire, cable, or bus bar.

CONFINED SPACE: A working space with a limited means of egress or entry that is not designed for routine employee entry such as a manhole, vault, tunnel, or shaft.

CONTRACTOR: An organization or person, not a part of the contracting entity, hired to perform a particular function or provide a particular product.

COVERED CONDUCTOR: A conductor covered with a material having no rated insulating strength or having a rated insulating strength less than the voltage of the circuit in which the conductor is used.

DE-ENERGIZED: Free from any electrical connection to a source of potential difference and from electric charge (i.e., not having a potential difference from that of earth). A conductor can only be considered de-energized if a deliberate connection is made between that conductor and ground.

DESIGNATED PERSONNEL (DESIGNATED PERSON): (See Authorized Personnel.)

DESIGNEE (ACTIVITY SUPERVISOR OR KNOWLEDGEABLE PERSON): One who is recognized by laboratory management as having a sufficient understanding of an experimental device or facility (i.e., the activity) to be able to positively identify and control the hazards it could present.

DIELECTRIC TESTING: A controlled method used to test the electrical safety integrity of electrical personal protective and live-line equipment.

ELECTRICAL HAZARD: A potential source of personnel injury, resulting either directly or indirectly from the use of an electrical energy source.

- **DIRECT ELECTRICAL HAZARD:** Potential source of personnel injury resulting from the flow of electrical energy through a person's body (potential electrical shock and burns).

- **INDIRECT ELECTRICAL HAZARD:** A potential source of personnel injury resulting from electrical energy transformed into other forms of energy (e.g., radiant energy, such as RF energy, light, and heat, energetic particles, mechanical forces, and chemical reactions such as fire and the production of noxious gases and compounds).

ELECTRICAL SAFETY INSPECTOR: A person qualified by education, experience, accreditation or certification, who has been approved by the AHJ to perform electrical safety inspections.

ELECTRICAL WORKER: (See Qualified Electrical Worker)

EMERGENCY-SHUTDOWN PUSHBUTTON: A control device provided to automatically remove electrical energy to devices in the area during an emergency.

ENERGIZED: Electrically connected to a source of potential difference, or electrically charged so as to have a potential significantly different from that of earth in the vicinity.

ENGINEERED SAFETY SYSTEM (ESS): A system especially designed for the protection of life, limb, and property. Such systems may be commercial (as in the Fire Protection System) or they may be locally engineered (as in the Laser Safety Interlock System and the X-ray Barrier System).

EQUIPMENT POWER WIRING (See also the definition of Small Signal and ADP Wiring): Power conductors from the wall power source to, from and within the equipment.

ESCORT (NON-SECURITY): A QEW accompanying non-qualified employees, or visitors, in the vicinity of electrical equipment or lines.

EXPOSED: Not isolated, not insulated or not guarded.

EXPOSED PARTS: Exposed parts (as applied to live work) are items capable of being inadvertently touched or approached nearer than a safe distance by a person. This applies to parts not suitably guarded, isolated, or insulated.

FAILSAFE: Built-in safety characteristics of a unit or system so that a failure (of the unit or system) or a loss of control power will not result in an unsafe condition.

FIRST-LINE PROTECTION: The primary protective system and operating procedures to prevent physical contact with energized equipment by personnel.

FIRST-LINE SUPERVISOR: The position assigned by upper management to provide scheduling, direct supervision, and evaluation of work for an employee as a "first-line supervisor." The position is part of line management and is also responsible for personnel actions including hiring, terminations, discipline, and pay changes for employees supervised.

FLASH PROTECTION BOUNDARY: An approach limit at a distance from exposed live parts within which a person could receive a second-degree burn if an electrical arc flash were to occur.

GENERAL ACCESS AREA: Areas that do not present hazards to personnel while equipment and systems are functioning normally. These areas are accessible to all personnel.

GROUND:

- **EFFECTIVELY GROUNDED:** Intentionally connected to the earth through a ground connection or connections of sufficient low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazard to connected equipment or persons.

- **EQUIPMENT GROUND:** The conductor that is used to connect the grounding electrode to the equipment required to be grounded. This conductor does not normally carry current.

GROUND FAULT CIRCUIT INTERRUPTER (GFCI): A device used to detect current leakage to ground at the 5 ± 1 mA level and which acts to interrupt the circuit for personnel protection purposes. This is known as a Class A GFCI device. Other classes of GFCI devices exist, but they are not referenced in this manual nor do they satisfy the requirements of this document.

GROUNDED CONDUCTOR: A conductor that is intentionally grounded to supply a system reference and carry current back to the source. This conductor is designed to carry current.

GROUNDING: The act of providing "an intentional connection" to earth through a ground connection of sufficiently low impedance and having sufficient current carrying capacity to prevent the build-up of voltage which could result in undue hazard to connected equipment or to people.

GROUNDING CONDUCTOR: The conductor used to connect the grounded conductor to the system grounding conductor.

GROUNDING HOOK: A device for making a temporary connection to discharge and ground the internal energy sources in hazardous electrical equipment. It consists of a bare copper rod shaped like a shepherd's hook at one end, an insulating handle, and a suitable bare flexible copper cable securely connected at the other end, which in turn is clearly visible through its insulating sheath and securely connected to an equipment or building ground.

GROUNDING POINTS: The most direct connections possible for the protective grounding of a source of stored energy (e.g., capacitor terminals).

GROUP LEADER/SECTION LEADER: The person with the direct accountability for the area in which identified electrical activity has taken place, or will take place. The group leader has responsibility for the safety of work that is to be performed and is familiar with the hazards.

GUARDED: Protected by means of a suitable covering, casing, barrier, rail, screen, mat, or platform that minimizes accidental contact by persons or objects. Conductors which are insulated, but are not otherwise protected, are not considered to be guarded under normal conditions.

HAZARDOUS ATMOSPHERE: An atmosphere presenting a potential for death, disablement, injury or acute illness.

HIGH CURRENT, LOW VOLTAGE: A circuit operating at 50 V or less shall be treated as a hazardous circuit if the power in it can create electrical shocks, burns, or an explosion due to electric arcs. Inductive circuits may create high-voltage hazards when interrupted.

HIGH HAZARD: A high hazard situation exists when the hazard situation is accompanied by a necessity to perform manipulative operations at the hazard location.

HIGH VOLTAGE: Voltages greater than 600 volts.

INSULATED: Separated from other conducting surfaces by a dielectric substance (including air space) offering a high resistance to the passage of current.

INSULATED CONDUCTOR: A conductor covered with a dielectric material having a rated insulating strength equal to or greater than the voltage of the circuit in which it is used.

INTERLOCKED ACCESS AREAS: Areas in which the sources of power must be interlocked with the access doors because of the hazards contained therein. (See Engineered Safety Systems).

ISOLATED: An object is isolated when: i) it is not readily accessible to persons without special means of access; and ii) its energy sources have been removed, i.e., all isolation devices are locked open and any fuses associated with potential devices or other power supplies have been removed.

ISOLATING DEVICE: A physical device that prevents the transmission or release of electrical energy such as, but not limited to, a draw-out circuit breaker, disconnect switch, or other similar device with a visible indication of the position of the device. (Push buttons, selector switches, and other control-circuit type devices are not energy isolating devices).

KNOWLEDGEABLE PERSON (ACTIVITY SUPERVISOR OR DESIGNEE): (See Activity Supervisor or Designee)

LABELED: (See Accepted)

LIMITED ACCESS AREAS: Areas that are kept locked and are accessible only to authorized personnel because of the hazards contained therein.

LIMITED APPROACH BOUNDARY: An approach limit at a distance from an exposed live part within which a shock hazard exists.

LISTED: (See Accepted.)

LIVE (ENERGIZED) WORK: Live (Energized) work is any work performed close enough to Exposed Parts of electrical circuits and equipment operating at 50 volts or more to ground for a hazard to exist.

LIVE-LINE TOOLS: Live line tools are any wooden or fiberglass rod or pole, rated for the voltage involved, used to touch or come in proximity to energized or potentially energized conductors or exposed electrical equipment parts. (It is recommended that only fiberglass material be utilized.)

LOCK AND TAG PROCEDURES: Written procedures covering (a) the use of padlocks or other key locks to ensure that energy-supply disconnect devices are maintained in the open position for safe work on equipment, (b) the use of easily recognizable tags attached to the disconnect device control, that identify pertinent information about the work being performed, (c) the designation of authorities for the work and for safety actions to be taken, (d) the logging of dates, times, and signatures for the work being performed, and (e) other information necessary to ensure the safety of personnel and the protection of equipment, both during the work and when the energy supply is restored after the work is completed.

LOCKED/LOCKED OUT: Protected by lock in such a manner that an isolating device cannot be inadvertently closed or operated without removing the lock.

LOCKOUT: The placement of a lockout device on an energy isolating device in accordance with Ames Laboratory's established lockout-tagout procedure, ensuring that the energy isolating device and the equipment being controlled cannot be operated until the lockout device is removed.

LOCKOUT DEVICE: A device that utilizes a positive means, such as a keyed lock to hold an energy isolating device in the safe position to prevent energizing a machine or equipment.

LOW VOLTAGE: Voltages 600 volts or less.

MASSIVE GROUND: Large areas of grounded metal surfaces on or adjacent to equipment (e.g., equipment supports, enclosures, and floor gratings) or earth in the case of outdoor equipment, which make isolation difficult or impossible for the protection of personnel working on energized electrical equipment.

MAY: Denotes permission (neither a requirement nor a recommendation).

MOBILE EQUIPMENT: Includes, but is not limited to, cranes, line trucks, aerial lifts, and similar types of equipment.

MUST: Mandatory and denotes a requirement.

NATIONAL CONSENSUS STANDARD: Any standard or modification thereof which: (1) has been adopted and promulgated by a nationally recognized standards-producing organization under procedures whereby it can be determined by the Secretary of Labor or by the Assistant Secretary of Labor that persons interested and affected by the scope or provisions of the standard have reached substantial agreement on its adoption; (2) was formulated in a manner which afforded an opportunity for diverse views to be considered; and (3) has been designated as such a standard by the Secretary or the Assistant Secretary, after consultation with other appropriate Federal agencies.

NATIONAL ELECTRICAL CODE (NEC): A manual published by the National Fire Protection Association and updated every three years. The purpose of this code is the practical safeguarding of persons and property from hazards arising from the use of electricity.

NATIONALLY RECOGNIZED TESTING LABORATORY (NRTL): An organization recognized by OSHA which tests for safety, and which lists, labels, or accepts equipment or materials that meet OSHA testing criteria.

NEAR PROXIMITY: A minimum clearance of 10 feet (305 cm) between equipment and energized lines 50 kv or less. This distance increases 4 inches (10 cm) for every 10 kv over 50 kv. See Ten (10) Foot Rule.

NON-INSULATED CONDUCTOR: A conductor that is neither covered nor insulated and has no insulating properties other than air.

OPERATING PROCEDURE (OP): A written document detailing safe and proper operations to accomplish a task. Operating procedures shall be reviewed and approved by a line manager with expertise in the area of operation.

OPERATING SYSTEM LOCK: A keyed lock placed on the high voltage distribution system to prevent unintentional opening of a disconnect/switch. Operating system locks may be unique or common lock systems.

PERSON-IN-CHARGE (PIC): A program director/department manager/group leader/section leader, shop manager, team supervisor, or a person appointed by them, to be in charge of a work area.

PERSONAL PROTECTIVE EQUIPMENT (PPE): Equipment or devices designed to provide workers with isolation or protection from hazardous materials, injurious radiation, flying objects, dangerous energy, or other unsafe environmental conditions.

PERSONNEL SAFETY INTERLOCK SYSTEM: Identifies one or more of the emergency-shutdown systems or personnel access control systems or both. (See Engineered Safety System).

PORTABLE ELECTRICAL EQUIPMENT: Electrical equipment designed to be hand held in operation. This includes portable electric tools, trouble lamps, and similar utilization equipment.

POSITIVELY DE-ENERGIZED: All external sources of electrical energy are disconnected by some positive action (e.g., a locked-out switch or circuit breaker) and all internal energy sources (e.g., capacitor energy storage) are made safe by discharging and grounding.

POTENTIALLY ENERGIZED: A non-insulated conductor or device that, by nature of design or location, may be energized by an adjacent energized conductor, switch closure, or back-feed.

PROHIBITED APPROACH BOUNDARY: An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part.

PROXIMITY: Close enough for a person to reach, fall into, or otherwise accidentally contact energized or potentially energized conductors and/or exposed electrical equipment.

QUALIFIED DESIGNEE (QD): See person-in-charge.

QUALIFIED ELECTRICAL WORKER (QEW): An individual who is a qualified worker on electrical systems in accordance with the Electrical Safety Manual-Training Requirements Policy (46200.003), see Chapter 3.

QUALIFIED PERSON: A qualified person shall be trained and knowledgeable of the construction and operation of equipment or a specific work method and be trained to recognize and avoid the electrical hazards that might be present with respect to that equipment or work method.

(a) Such persons shall also be familiar with the proper use of the special precautionary techniques, personal protective equipment, including arc-flash, insulating and shielding materials, and insulated tools and test equipment. A person can be considered qualified with respect to certain equipment and methods but still be unqualified for others.

(b) An employee who is undergoing on-the-job training and who, in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person shall be considered to be a qualified person for the performance of those duties.

(c) Such persons permitted to work within the Limited Approach Boundary of exposed live parts operating at 50 volts or more shall, at a minimum, be additionally trained in all of the following:

- The skills and techniques necessary to distinguish exposed energized parts from other parts of electrical equipment
- The skills and techniques necessary to determine the nominal voltage of exposed live parts
- The approach distances specified in Table 130.2(C) and the corresponding voltages to which the qualified person will be exposed
- The decision-making process necessary to determine the degree and extent of the hazard and the personal protective equipment and job planning necessary to perform the task safely

Employees working on or near exposed energized electrical conductors or circuit parts shall be trained in methods of release of victims from contact with exposed energized conductors or circuit parts.

RACEWAY: A raceway is an enclosed channel designed expressly for holding wires, cables, or bus bars. Raceways may be metal or insulating material and include all types of conduit, tubing, under floor raceways, cellular concrete/metal floor raceways, surface raceways, wire ways, and busways.

RESTRICTED APPROACH BOUNDARY: An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part.

RUBBER PROTECTIVE EQUIPMENT: Insulating material including elastomers and elastomer compounds, regardless of origin.

SAFE WORK PERMIT (SWP): Used to control the conduct of hazardous operations, tests, or experiments by line organizations. Pertains to activities performed a limited number of times outside the scope of existing SOPs because of unforeseeable or changing conditions. Form 46200.010.

SAFETY BARRIER: A safeguard installed to restrict personnel access to a hazardous area.

SAFETY COORDINATOR/SAFETY REPRESENTATIVE (SC/SR): Individuals who act as liaisons between research groups and other entities in the Laboratory. Communication and/or dissemination of information by a group's SC/SR to employees and vice versa is intended to facilitate implementation of Laboratory and program and/or group specific safety programs.

SAFETY INTERLOCK: An electrical or mechanical device that prevents operation of equipment or precludes access to hazardous areas, enclosures, or equipment.

SAFETY LOCK: A controlled keyed lock, whose intent is personnel protection only, that would be installed at each lockout/tagout location in conjunction with a switching clearance. This is a unique lock system.

SAFETY SYSTEM REVIEW (SSR): The Safety System Review (SSR) document (prepared by FES-Electronics) describing the design of a system. In general it enumerates the system features and describes the reasons that such features should be incorporated. For Engineered Safety Systems (or other designs where special concerns exist) this document details the features used to mitigate items specifically addressed by the Safety Analysis Review.

SAFETY WATCH: A person whose specific duties are to observe the workers and operations being performed, prevent careless acts, quickly de-energize the equipment in emergencies, and alert emergency rescue personnel. This person shall have current cardiopulmonary resuscitation (CPR) certification and shall be thoroughly instructed on the locations of emergency shutoff switches and power disconnects and on the specific working procedures to be followed.

SHALL: Mandatory and denotes a requirement.

SHOULD: Optional, but highly recommended.

SMALL SIGNAL AND ADP WIRING: Wiring methods used with permanent or temporary R&D equipment/wiring installations for control, signaling, data communication, and data acquisition, normally under 50 volts and low current.

TAGOUT DEVICE: A prominent warning device, such as a tag and a means of attachment, which can be securely fastened to an energy isolating device in accordance with Ames Laboratory's Lockout/Tagout operating procedure. This device indicates that the energy isolating device and the equipment being controlled may not be operated until the tagout device is removed.

TAGOUT: The placement of a tagout device on an energy isolating device in accordance with an established procedure, to indicate that the energy isolating device and the equipment being controlled may not be operated until the tagout device is removed.

TEMPORARY WIRING: Wiring methods that may be of a class less than would be required for a permanent installation. Anytime there is an active effort to install a system or any R&D project equipment such that it is intended to last for a limited period of time. (Temporary wiring shall be removed immediately upon completion of the project.)

UNAUTHORIZED WORKER: An individual who has no authorization to enter a location.

UNDERGROUND FACILITY: A facility built below ground surface.

WILL: Mandatory and denotes a requirement.

WORKING NEAR (LIVE PARTS): Any activity inside a Limited Approach Boundary.

ACRONYMS

AC	alternating current
AHJ	authority having jurisdiction
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
AWG	American Wire Gauge
CB	circuit breaker
CFR	Code of Federal Regulations
CMAA	Crane Manufacturers Association of America
CPR	cardiopulmonary resuscitation
DC	direct current
DOE	Department of Energy
EED	electro-explosive device
EPM	electrical preventive maintenance
ESC	Electrical Safety Committee
ESH&A	Environment, Safety, Health and Assurance
FES	Facilities & Engineering Services
FMEC	Factory Mutual Engineering Corporation
GFCI	ground fault circuit interrupter
GFP	ground fault protector
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
MCC	Motor Control Center
MTS	Member of Technical Staff
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NRTL	National Recognized Testing Laboratory
OSHA	Occupational Safety and Health Administration
OSQA	Office of Safety and Quality Assurance
OP	operating procedure
PCB	polychlorinated biphenyl
PIC	person-in-charge
PPE	personal protective equipment
QEW	qualified electrical worker
QD	qualified designee
R&D	research and development
RF	radio frequency

SWD	switch rated device
SWP	safe work permit
SSR	safety system review
TPT	temporary power taps
UBC	Uniform Building Code
UL	Underwriters Laboratory, Inc.
UPS	uninterruptable power supply

Appendix B
REFERENCES

American National Standards Institute
- ANSI/RP-7-91 Industrial Lighting
- ANSI/UL 45, "Portable Electric Tools"
- ANSI/UL 698, "Industrial Control Equipment for Use in Hazardous Locations"
- Z41 Protective Footwear
- Z87.1 Practice for Occupational Eye and Face Protection
- Z89.1 Protective Headwear for Industrial Workers Requirements
- Z136.1 Safe Use of Lasers

American Society of Mechanical Engineers
- ASME/ANSI 17.2, "Inspectors Manual for Elevators and Escalators"
- ASME/ANSI 17.3, "Safety Code for Existing Elevators and Escalators"
- ASME/ANSI A17.1, "Safety Code for Elevators and Escalators"

CFR (Code of Federal Regulations)
- 29CFR (Title 29 - Labor)
- Part 1910 - Occupational Safety and Health Standards (Volumes 1 and 2)
- Part 1926 - Safety and Health Regulations for Construction

Department of Energy Orders, Manuals, and Handbooks
- DOE O 440.1, "Worker Safety"
- DOE O 420.1, "Facility Safety"
- DOE Handbook, Electrical Safety, No. DOE-HDBK-1092-2004

National Fire Protection Association
- NFPA, "National Fire Codes"
- NFPA 70, "National Electrical Code"
- NFPA 70B, "Recommended Practice for Electrical Equipment Maintenance"
- NFPA 70E, "Standard for Electrical Safety in the Workplace"
- NFPA 71, "Installation, Maintenance, and Use of Signaling Systems for Central Station Service"
- NFPA 72, "Installation, Maintenance, and Use of Protective Signaling Systems"
- NFPA 77, "Recommended Practice on Static Electricity"
- NFPA 78, "Lightning Protection Code"
- NFPA 101, "Life Safety Code"
- NFPA 325M, "Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids"
- NFPA 493, "Intrinsically Safe Apparatus in Class I Hazardous Locations"
- NFPA 496, "Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Locations"
- NFPA 497M, "Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous Classified Locations"

Ames Laboratory
- Environment, Safety, Health and Assurance Program Manual (10200.002)

Appendix C
UNDERSTANDING ELECTRICAL SAFETY

Electricity is a pure form of energy that is utilized throughout the world. Most electrical energy is generated in power plants that burn coal, oil, or natural gas as the source of fuel or use atomic power. While electricity is necessary in general industry, there are certain hazards associated with its use, and these hazards must be understood and avoided. The hazards most dangerous to employees are created by electrical arcs, electrically generated heat, electrocution, and explosions. The material in this appendix deals with such hazards.

Maintaining a Safe Electrical Environment
A safe electrical environment depends primarily on a properly designed, installed, operated, and maintained installation, but also on adequate employee qualification and training. There are many standards that govern electrical installation and maintenance and the training and qualification of personnel. Such standards include the following:

- 29 CFR1910, Subpart S;
- 29 CFR1926, Subparts K and V;
- NFPA 70, National Electrical Code (NEC);
- IEEE C-2, National Electrical Safety Code (NESC);
- NFPA 70B, Recommended Practice for Electrical Equipment Maintenance; and
- NFPA 70E, Standard for Electrical Safety in the Workplace.

These codes, requirements, and standards shall be followed as a minimum to ensure that an electrically safe workplace is provided. Procedures for proper maintenance after installation must be followed to ensure that the electrical systems are maintained in a safe, reliable condition.

The National Safety Council estimates that 31% of all known electrocutions occur in the home, 24% occur in general industry, and the remaining 45% occur in the generation and distribution of electrical power. This means that approximately 55% of all electrocutions are caused by contact with so-called low-voltage circuits, rated at 600 volts or less.

Every piece of electrical equipment is a potential source for an electrical hazard, which makes the design, operation, installation, and maintenance of this equipment of the utmost importance. Electrical equipment that is serviced and maintained in a proper manner provides the best possible protection from electrical hazards for employees working near or in their workplaces.

Before discussing electrical hazards, it is necessary to get acquainted with some electrical terms and how they are used. The more important terms are as follows.

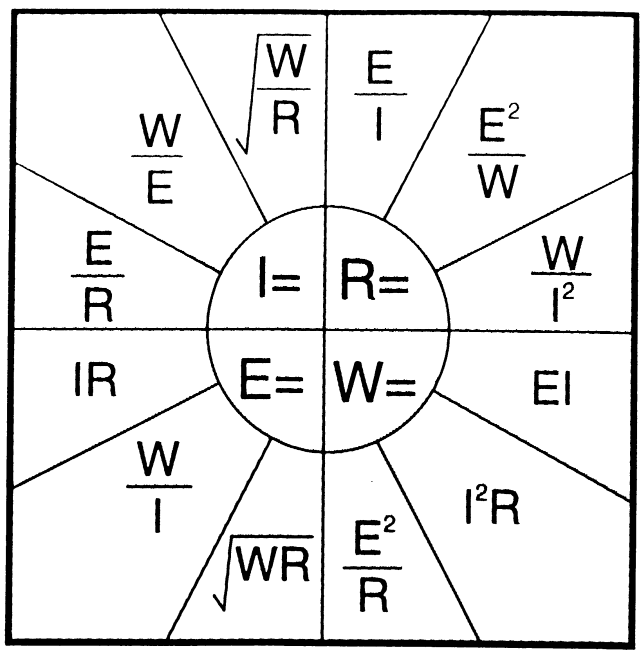
- <u>Voltage (electromotive force)</u>, measured in volts and represented by the letter V (or E), is the electrical pressure required to deliver energy to do the work, such as to turn a motor, to light a bulb, or to produce heat. Voltage in an electrical circuit is comparable to water pressure in a water line.
- <u>Current</u>, measured in amps and represented by the letter I, is the component that does the work. Like water pressure moves water in a water line, voltage moves current from one location to another in the electrical circuit.
- <u>Resistance</u>, measured in ohms and represented by the letter R, restricts the flow of current in a circuit component.

- A <u>conductor</u> is used to deliver current to a specified location. Its resistance is usually very low and is inversely proportional to its cross sectional area.

- An insulator is a material of very high resistance used to prevent current (electrons) from escaping from a conductor.
- Reactance is the reaction of capacitors (capacitive reactance, X_C,) or inductors (inductive reactance, X_L,) to the constantly changing polarity in alternating current circuits. Its effect is to reduce alternating current flow in much the same way that resistance does.
- Impedance is the combined effect of resistance and reactance, is represented by the letter Z, and is expressed as: $Z = [R^2 + (X_L - X_C)^2]^{1/2}$.
- Power, measured in watts and represented by the letter P (or W), is the rate at which work is performed in the utilization of electricity.

Ohm's Law

Voltage, current, and resistance are all linked by Ohm's Law. Ohm's Law simply states that 1 volt causes a current of 1 amp to flow through a resistance of 1 ohm. This relationship is expressed as the formula: E (volts) = I (amps) x R (ohms). These relationships can be broaden to include power in watts as is shown in Figure C-1.



W = POWER (WATTS)
R = RESISTANCE (OHMS)
I = CURRENT (AMPS)
E = VOLTAGE (VOLTS)

Figure C-1 Graphical Representation of Ohm's Law

An easy way to remember this formula and the different ways it can be expressed is to put the symbols in a circle and place your finger on the value you are trying to find (See Figure C-2.).

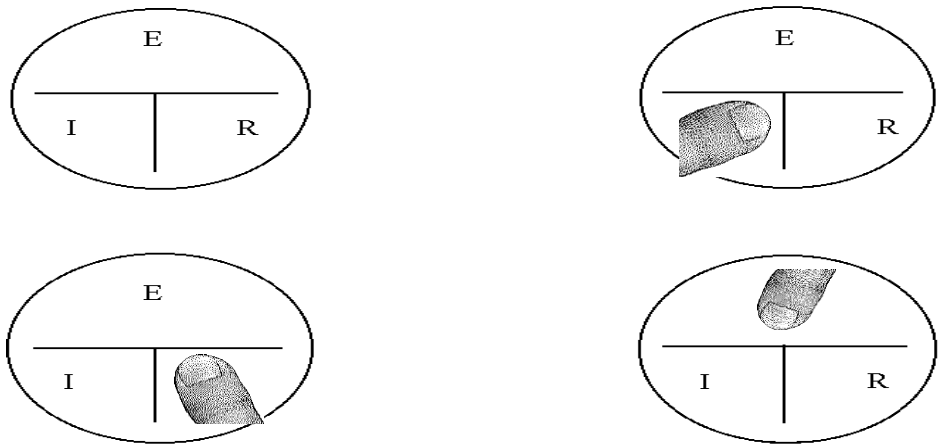


Figure C-2 Pictorial

By placing your finger on the unknown value, the remaining two letters give the formula to use for finding the unknown value.

Finding Voltage

The voltage in an electrical circuit is determined by multiplying the current (I) by the resistance (R). To derive the formula for finding the voltage in a resistive electrical circuit, simply place your finger over the unknown value in Fig. C-2, (E = I x R).

For example, the voltage (E) in an electrical circuit having a current (I) of 12 amps and a resistance (R) of 10 ohms can be found as follows:

Step 1: Find the formula using Figure C-2 E = I x R Step 2: Apply formula E = 12 amps x 10 ohms E = 120 volts Solution: The voltage in the electrical circuit is 120 volts.

Finding Current

The current in an electrical circuit is determined by dividing the voltage (E) by the resistance (R). To derive the formula for finding the current in a resistive electrical circuit, place your finger over the unknown value in Fig. C-2, (I = E / R).

For example, the current in a resistive electrical circuit having a voltage of 120 volts and a resistance of 20 ohms can be found as follows:

Step 1: Find the formula using Fig. C-2
I = E / R

Step 2: Apply the formula
I = 120 volts / 20 ohms
I = 6 amps

Solution: The current in the electrical circuit is 6 amps.

Finding Resistance

The resistance (R) in an electrical circuit is determined by dividing the voltage (V) by the current (I). To derive the formula for finding the resistance in a resistive electrical circuit, place your finger over the unknown value in Fig. C-2, (R = E / I).

For example, the resistance (R) in an electrical circuit having a voltage (V) of 120 volts and a current (I) of 5 amps can be found as follows:

Step 1: Find the formula using Fig. C-2
R = E / I

Step 2: Apply the formula
R = 120 volts / 5 amps
R = 24 ohms

Solution: The resistance in the electrical circuit is 24 ohms.

Finding Impedance
The Ohm's Law formula applies to direct current (dc) circuits. However, in alternating current (ac) usage, Ohm's Law becomes E = I x Z, where Z is the impedance of the circuit. As discussed above, impedance is the sum of the resistance and reactance, and is expressed as:

$$Z = [R^2 + (X_L - X_C)^2]^{1/2}$$

For example, what is the impedance (Z) in an AC circuit with a resistance (R) of 12 ohms, an inductive reactance (X_L)of 14 ohms, and a capacitive reactance (X_C) of 6 ohms?

Step 1: Find formula, text

$$Z = [R^2 + (X_L - X_C)^2]^{1/2}$$

Step 2: Apply the formula

$$Z = [12^2 + (14-6)^2]^{1/2}$$
$$Z = [144 + 64]^{1/2}$$
$$Z = [208]^{1/2}$$
$$Z = 14.42 \text{ ohms}$$

Solution: The impedance in the electrical circuit is 14.42 ohms.

Power
Another important electrical relationship is that between voltage (E), current (I), and power utilization (P). This relationship is expressed by the formula:

Power (P) = Current (I) x Volts (E).

An easy way to remember this formula and the different ways it can be expressed is to put the symbols in a circle and place your finger on the value that you are trying to find as shown in Figure C-3.)

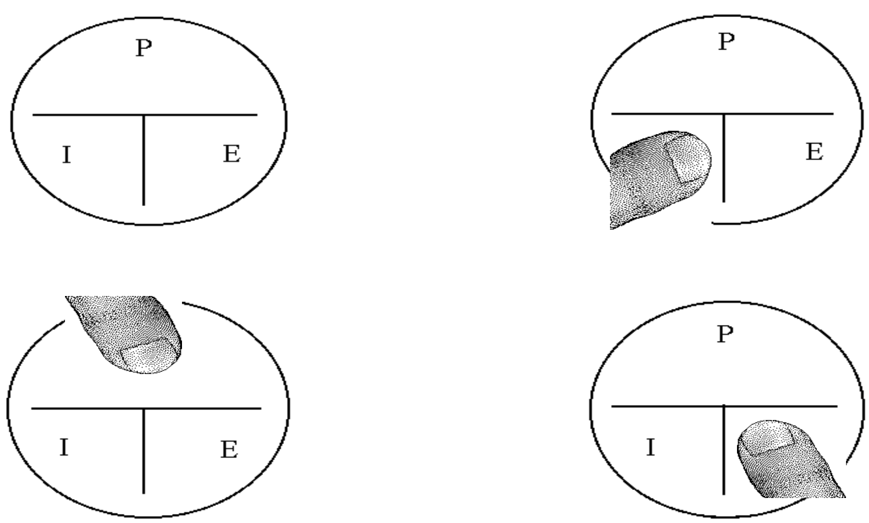


Figure C-3 Pictorial Electrical Relationship Between Power, Voltage and Current

By placing your finger on the unknown value, the remaining two letters will give the formula to use to find the unknown value.

Finding Power

The power in an electrical circuit is determined by multiplying the voltage (E) by the current (I).

For example, the power dissipated in an electrical circuit having a voltage of 120 volts and a current of 12 amps can be found as follows:

Step 1: Find the formula using Fig. C-3
P = I x E

Step 2: Apply the formula
P = I x E
P = 12 amps x 120 volts
P = 1,440 watts

Solution: The power in the electrical circuit is 1,440 watts.

Finding Current

The current in an electrical circuit is determined by dividing the power (P, or W) used by the voltage (E) applied to the circuit. To derive the formula for finding the current used in the circuit, simply place your finger over the unknown value shown in Fig. C-3 (I = P / E).

For example, the current flowing through a 6 watt light bulb that is being used in a 120 volt lamp socket can be found as follows:

Step 1: Find the formula using Fig. C-3
I = P / E

Step 2: Apply the formula
I = P / E
I = 6 watts / 120 volts
I = .05 amps = 50 milliamps

Solution: The current flow is 50 milliamps.

Basic Rules of Electrical Action

There are three basic rules of electrical action that take place in an electrical circuit. Personnel working on or near electrical circuits must be acquainted with the following:

- Electrical current won't flow until there is a complete loop, that is, a loop from the voltage source back to the voltage source.
- Electrical current always returns to its source.
- When current flows, work is accomplished.

Rule 1 explains that current will flow any time there is a way for the electricity to return to its source. If a bird is sitting on a power line, no current flows through the bird's body because there is no loop back to the transformer. Faulty power tools with live metal cases can be carried and used by employees without causing a shock until contact is made with a ground loop of low resistance.

Rule 2 explains the action that the current takes where a loop or path exists that returns to the source. In a grounded transformer secondary system, electrical current will not only use the earth as a return path, but any other loop path it can use to return to its secondary source. Water pipes, metal ventilation ducts, metal studs in modern wall construction, metal door frames, T-bars holding suspended ceiling panels, and metal ridge roll with a grounded lightning system are examples of other ground loops.

Rule 3 explains the action that current has on the body. Since the body is considered a resistive load, getting one's body in a current loop can cause injury. Hazardous voltage and current can cause irreversible body harm.

Great care must be exercised when employees are working near or with high-voltage systems. There is very little that can be done to increase the resistance of the body. This is why appropriate protective equipment such as rubber gloves, mats, blankets, and other insulating materials must be used.

Factors Enhancing Electrical Shock

The route that electrical current takes through the human body affects the degree of injury. The voltage pressure determines how much current flows. In cases where individuals come in contact with distribution lines, the high voltage causes the moisture in the body to heat so rapidly that body parts can literally explode. This extreme expansion is the result of the body fluids changing to steam, with an expansion ratio estimated to be 1 to 1,500. This could severely injure but not electrocute a person. When investigating shock incidents, whether these are near misses or those that have caused injury, these factors can be used as an investigative tool. Any report of a shock hazard should be checked. The combination of one or more of these factors can be analyzed and action taken to eliminate or control the hazard potential. Other factors that enhance electrical shock potential are as follows:

- Wet or damp locations;
- Ground/grounded objects;
- Path of current through body and duration of contact;
- Area of body contact and pressure of contact;
- Physical size, condition, and age of person;
- Type and amount of voltage;
- Personal protective equipment, gloves, and shoes;
- Metal objects such as watches, necklaces, rings, etc.;
- Poor workplace illumination;
- Color blindness;
- Lack of training or knowledge; and
- No safe work procedures.

Electrical Current Danger Levels

Because experiments on ventricular fibrillation cannot be performed on humans, animals have been substituted. The first work of this type was that of Ferris, Spence, King, and Williams of the Bell

Telephone Laboratories in 1936. Since that time, researchers at John Hopkins University and the Union of Soviet Socialist Republic Academy of Sciences have expanded the knowledge of the effects of electrical current on humans. As a result, the danger threshold for ventricular fibrillation was established for typical adult workers.

From Figure C-4, one can determine that a 100 mA current flowing for 30 seconds through a human adult body will cause death by electrocution. This doesn't seem like much current when you consider that a small, light-duty portable electric drill draws 30 times that amount. However, because a current as small as 30 mA (3/1000 amp) can cause painful shock, it is imperative that all electrical equipment plugs and cords and extension cords be kept in good condition and connected to a properly wired circuit with an equipment grounding conductor (EGC).

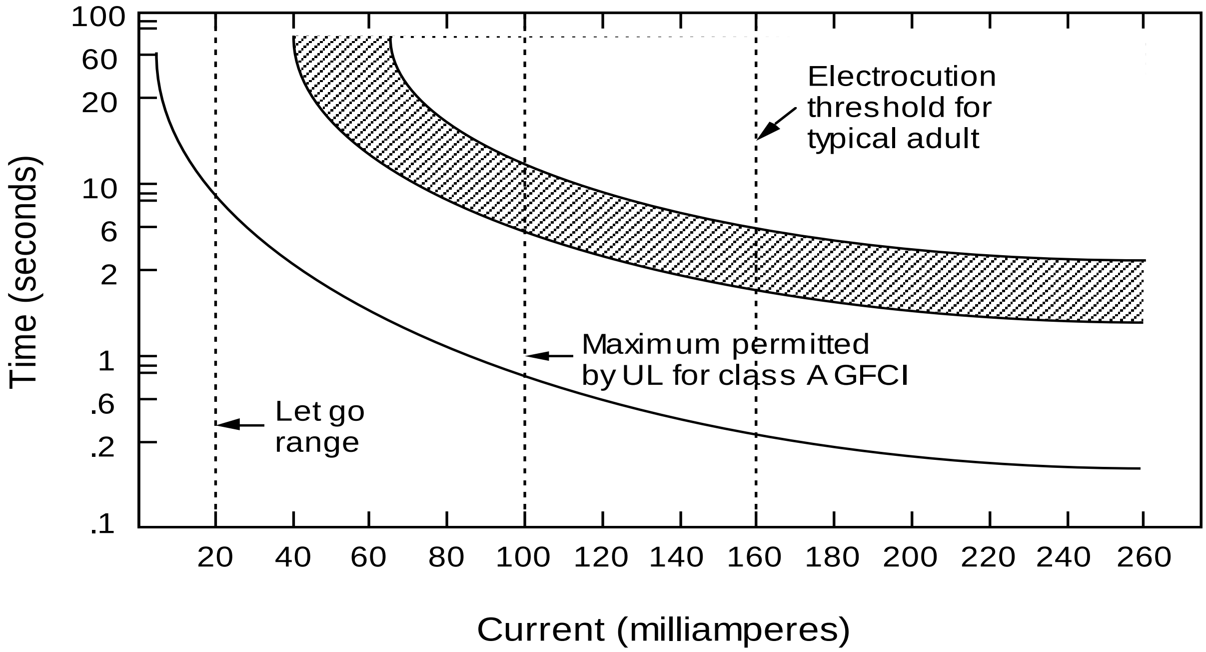


Figure C-4 Chart Shows Effects of Electric Current Intensity vs. the Time it Flows Through the Human Body

Table C-1 plots the range of electrical values that affect humans. Also shown is the requirement of UL for a Class A ground fault circuit interrupter (GFCI) intended for personnel protection. Note the time-current relationship at much lower currents and shorter time periods. The electrical current range, causing freezing (called the "let go" range), is also illustrated.

Table C-1. Current and its Effect on the Human Body

	Current in Milliamperes					
			Alternating			
	Direct		60 Hz		10,000 Hz	
Effect	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7	5
Perception threshold	5.2	3.5	1.1	0.7	12	8
Shock-not painful, muscular control not lost	9	6	1.8	1.2	17	11
Shock-painful, muscular control not lost	69	41	9	6	55	37
Shock-painful and severe, muscular contractions, breathing difficult	90	60	23	15	94	63
Shock-possible ventricular fibrillation effect from 3 second shocks	500	500	100	100		
Short shocks lasting t seconds			$165/\sqrt{t}$	$165/\sqrt{t}$		
High voltage surges	50[a]	50[a]	13.6[a]	13.6[a]		

a. Energy in watt-seconds or joules.

NOTE: Data are based on limited experimental tests and are not intended to indicate absolute values.

Body Resistance Model

The human body impedance has three distinct parts: internal body resistance and the two skin impedances associated with contact to surfaces of different voltage potential. The internal body impedance is reported to be essentially resistive with no reactive components. If the voltage applied is high, the skin impedance can be considered negligible. Contrary to beliefs, low current is dangerous and it doesn't necessarily require high voltage to kill.

A body resistance model shown in Figure C-5 indicates approximately 1,000 ohms from hand-to-hand or about 1,100 ohms from hand-to-foot. The greatest number of injurious shocks involves a current pathway through either hand-to-hand or hand-to-foot. It is easy to analyze electrical shock hazards today. A small amount of current (50 mA) can cause the heart to go into ventricular fibrillation. The example given that a 6-watt bulb uses 50 mA of current when energized by 120 V simply means that merely the current required to light a 6-watt bulb is capable of causing death.

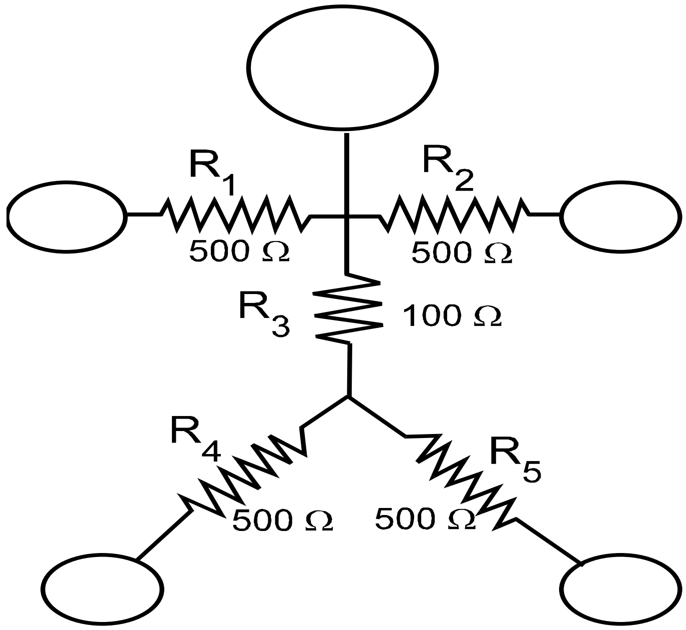


Figure C-5 Human Body Resistance Model

The resistance model of a person (Figure C-5), illustrates that wet contact with an energy source (such as 120 Vac) in one hand and a ground loop in the other produces current through the chest area equal to I = E/R = 120/1,000 = 0.12 amp or 120 mA; this current level is definitely hazardous. The current value in milliamps is determined by applying the following procedures:

Step 1: Finding formula mA = (E / R) x 1,000 Step 2: Finding resistance and voltage Figure D-4 Hand-to-hand ground loop resistance = 500 Ω + 500 Ω = 1,000 Ω Circuit = 120 V Step 3: Applying formula mA = (120V / 1,000 Ω) x 1,000 = 120 mA Solution: The current is 120 mA.

Note: Current level of 120 mA is definitely hazardous.

A case involving a worker using an ac welder illustrates the fact that less than 120 V can be hazardous. The welder was kneeling on a metal plate, wet with perspiration, and used the welding rod to scratch an itch on the back of his head, current flowed through to both knees. In this case the current through the neck, torso and both legs formed a series/parallel circuit. The resulting current flow would be approximately 228.6 mA with an 80 VAC source.

(I = E/R = 80/350 = .2286 amps = 228.6 mA.)

Note: The current and resistance values used in this example are approximate and are not intended to indicate absolute values. The actual values would be different for each individual involved. For example, full leg resistance was assumed.

The current in milliamps in the series/parallel circuit can be determined by the following procedure.

Step 1: Finding formula - Figure C-5

$$R_T = R_3 + \frac{(R_4\ R_5)}{R_4 + R_5}$$

Step 2: Finding resistance and voltage.
Figure D-4
Resistance: Head, torso,
through both knees - 100 Ω;
500 Ω; 500Ω;
Circuit = 80 V

Step 3: Applying Formula

$$R_T = 100\Omega + \frac{(500\Omega \text{ x } 500\Omega)}{500\Omega + 500\Omega}$$

$$R_T = 350\Omega$$

Step 4: Finding Milliamps

mA = (E÷R) x 1,000
mA = (80 V ÷ 350 Ω) x 1,000
mA = 228.6

Solution: The current is 228.6 mA.

Note: Current level of 228.6 mA is definitely hazardous.

Ventricular fibrillation is defined as repeated, rapid, uncoordinated contractions of the ventricles of the heart resulting in loss of synchronization between the heart beat and the pulse beat. Once ventricular fibrillation occurs, death will usually ensue in a few minutes. Resuscitation techniques, if applied immediately, can sometimes save the victim. Electric current flow is one of several things that can cause ventricular fibrillation.

Appendix E
Work Matrices

ELECTRICAL SAFETY REQUIREMENTS 50 to 150 V Line to Ground or 50 to 250 V Line to Line

Safety glasses are required for all electrical work

BACKUP PERSON (SAFETY WATCH)	Low Voltage Gloves (Rated)	B	B	B
	Qualified Electrical Backup Required	X	X	A
APPROVALS	Person-in-Charge (PIC) Approval	X	X	X
SAFETY EQUIPMENT	Other insulated protective equipment such as gloves, blankets, sleeves, mats, etc.	X	X	X
TOOLS	Insulated Hand Tools		X	
TEST EQUIPMENT	Other Approved Instrumentation	X	X	X
	Clamp Amp Meter			X
	Approved Multimeter	X		X
WORK DESCRIPTION		Probing Unknown Potentials	Adjustments	Voltage or Current Reading

For Work Descriptions not listed – see DOE Electrical Safety Handbook.
A = Backup person is not required if inadvertent contact with live parts is not possible.
B = Low voltage gloves are not required by the backup person if they can de-energize the equipment without contacting the worker in an emergency.
Electrical work that is covered by an approved Standard Operating Procedure may have different requirements than those listed in the matrix.

ELECTRICAL SAFETY REQUIREMENTS 151 to 250 V Line to Ground or 250 to 600 V Line to Line

Safety glasses are required for all electrical work

BACKUP PERSON	Low Voltage Gloves	X	X	X
	Qualified Electrical Backup Required	X	X	X
APPROVALS	Group Manager Approval			X
	Person-in-Charge (PIC) Approval	X	X	X
	Safe Work Permit Required	X		X
SAFETY REQUIREMENTS PROTECTIVE EQUIPMENT	Other insulated protective equipment such as gloves, blankets, sleeves, mats, etc.	X	X	X
	Face Shield			X
TOOLS	Insulated Hand Tools	X		X
TEST EQUIPMENT	Other Approved Instrumentation	X	X	X
	Clamp Amp Meter		X	
	Approved Multi-meter	X	X	X
WORK DESCRIPTION		Probing Unknown Potentials	Voltage or Current Reading	Other Work-Energized Circuits

For Work Descriptions not listed – see DOE Electrical Safety Handbook.
Electrical work that is covered by an Approved Standard Operating Procedure may have different requirements than those listed in the matrix.

ELECTRICAL SAFETY REQUIREMENTS – HIGH VOLTAGE, Greater than 600 V

Safety glasses are required for all electrical work

BACKUP PERSON	High Volt Gloves w/leather protectors		X	X		
	Qualified Electrical Backup Required		X	X		
APPROVALS REQUIRED	Safe Work Permit Required	X	X	X		
	Person-in-Charge (PIC) Approval	X	X	X		
	Safety Watch Approval		X	X		
SAFETY REQUIREMENTS PROTECTIVE EQUIPMENT	Insulated Surface		X	X	X	
	H.V. Gloves w/Leather Protect.	X	X	X	X	
	Face Shield		X			
	Lockout/Tagout (LO/TO)	X	X		X	X
TOOLS	Live Line Tools		X			
	Grounding Hook	X				X
TEST EQUIPMENT	Instrumentation as Approved by Supervisor	X	X	X	X	X
	High Pot				X	
WORK DESCRIPTION		Install/Remove Ground	Energized Work	Voltage Readings	High Potting De-Energized Equipment	Work De-Energized Equip.

For Work Descriptions not listed – see DOE Electrical Safety Handbook.
Electrical work that is covered by an Approved Standard Operating Procedure may have different requirements than those listed in the matrix.

ELECTRICAL SAFETY REQUIREMENTS – Batteries or Battery Banks

Safety glasses are required for all electrical work

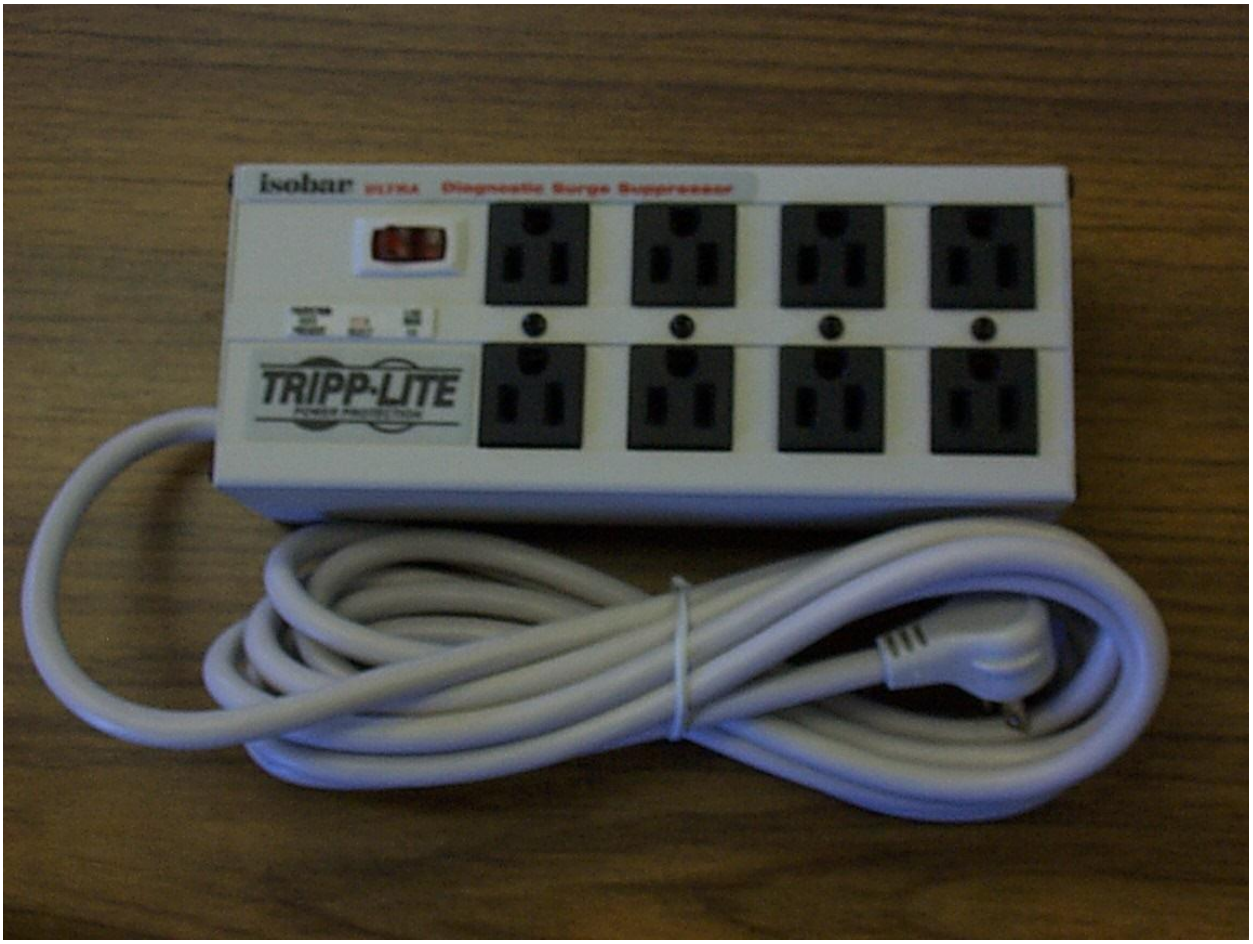
BACKUP PERSON	Face Shield				
	Latex Gloves and Apron				
	Qualified Electrical Backup Required				
APPROVALS	Person-in-Charge (PIC) Approval	X		X	X
SAFETY EQUIPMENT	Latex Gloves	X	X	X	X
	Acid Resistant Apron	X	X	X	X
	Lockout/Tagout (LO/TO)		X		X
	Face Shield	X	X	X	X
TOOLS	Insulated Hand Tools		X		X
TEST EQUIPMENT	Other Approved Instrumentation	X	X	X	
WORK DESCRIPTION		Voltage or Current Reading	Battery Rundowns	Equalize Batteries	Installation, Removal

For Work Descriptions not listed – see DOE Electrical Safety Handbook.
Electrical work that is covered by an Approved Standard Operating Procedure may have different requirements than those listed in the matrix.

Appendix F
Examples

Example: Power Centers

Minimum requirements: surge energy – 270 joules
Clamping voltage – 400 volts
EMI/RFI filter – 50 db from 100 KHz – 1 MHz
UL listed
Circuit breaker protected



Example: Power Taps

Minimum requirements: surge energy – 2300 joules
Clamping voltage – 350 volts
EMI/RFI filter > 80 db @ 1 Mhz
UL listed
Circuit breaker protected